SCIENCE PROGRAM SCIENCE SERVICE

MOON

MOON

SCIENCE PROGRAM

Prepared with the co-operation of
Science Service

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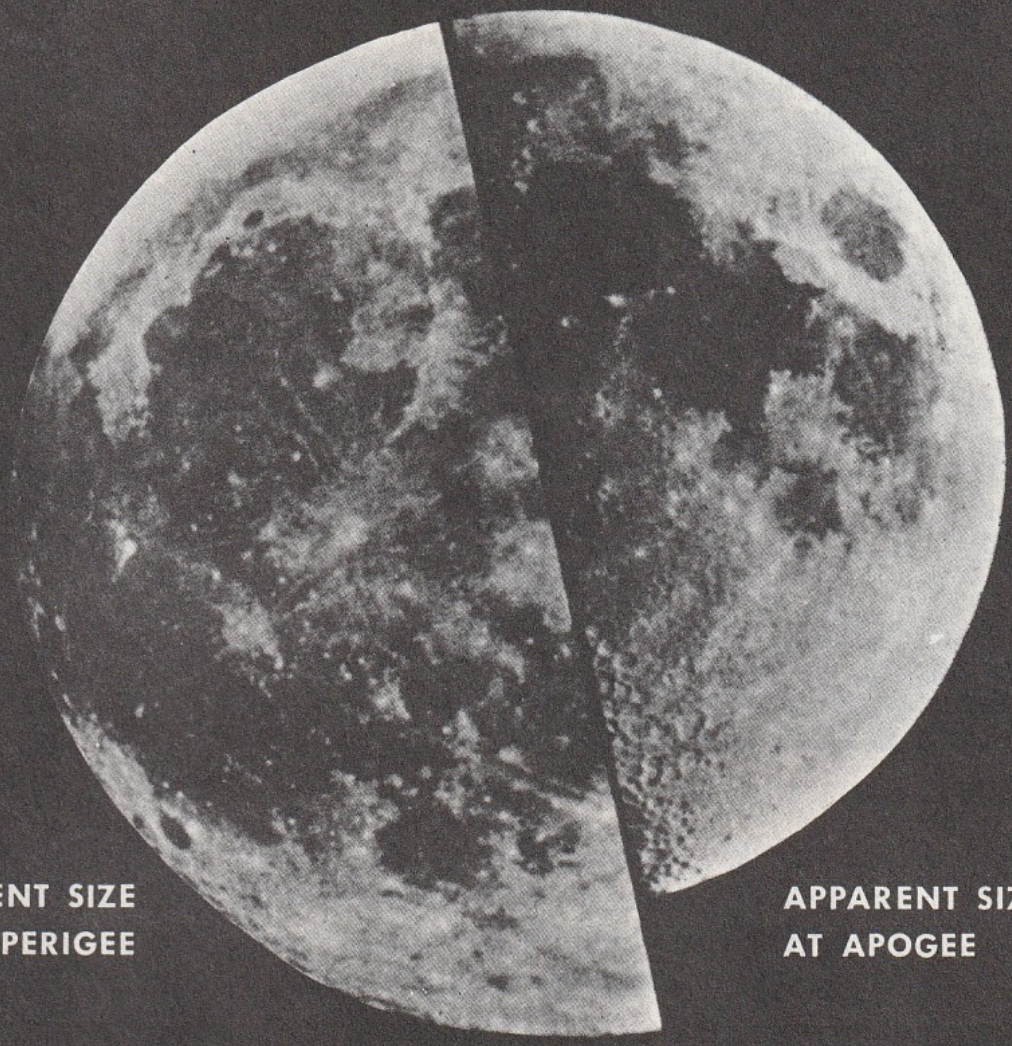
A New Look at an Old Neighbor

WHEN MAN REACHED OUT and touched the moon for the first time on 20 July, 1969—with the landing of two American astronauts in a spacecraft called *Eagle*—a dream of many centuries was fulfilled.

Since antiquity, earth's only natural satellite has been an object of awe, veneration and curiosity. The moon has been a source of mystery, an inspiration for legends, songs and poems. From earliest days, it has been man's aim to "conquer" his old neighbor.

Although the moon is not large as celestial bodies go—with a diameter only one-quarter that of earth—it is nevertheless fairly impressive in appearance. It is bright—only the sun appears more brilliant—and near

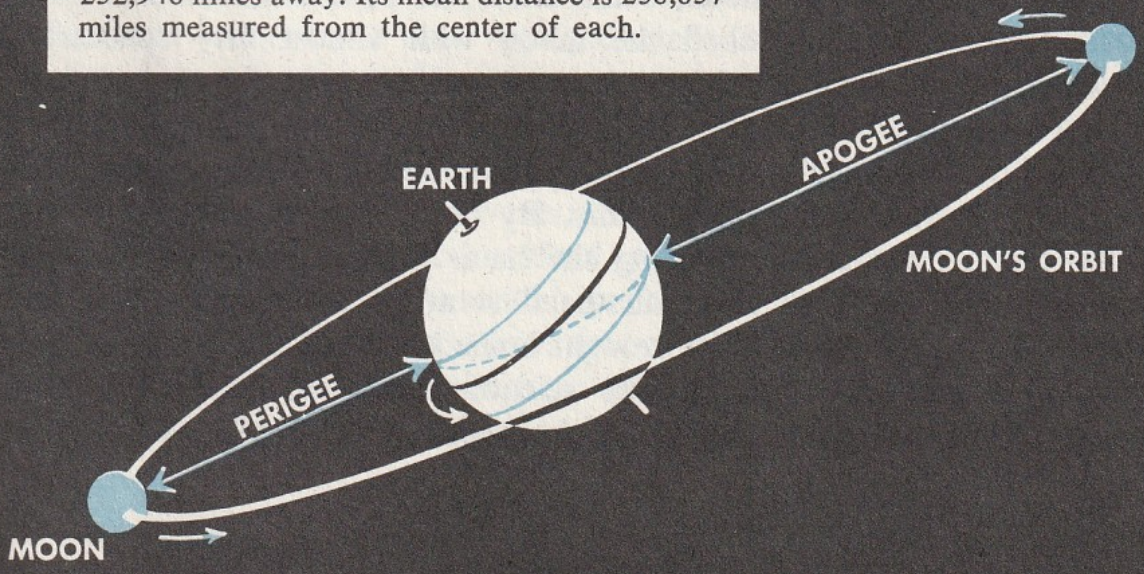
The full moon is by far the brightest object in the night sky, shining with light reflected from the sun. Notice the very bright patch near the moon's south pole. This is the crater Tycho and its vast system of rays reaching almost all the way across the moon. These rays, probably volcanic glass, mirror the sun's light. They are seen best at full moon when there are no shadows to obscure them.

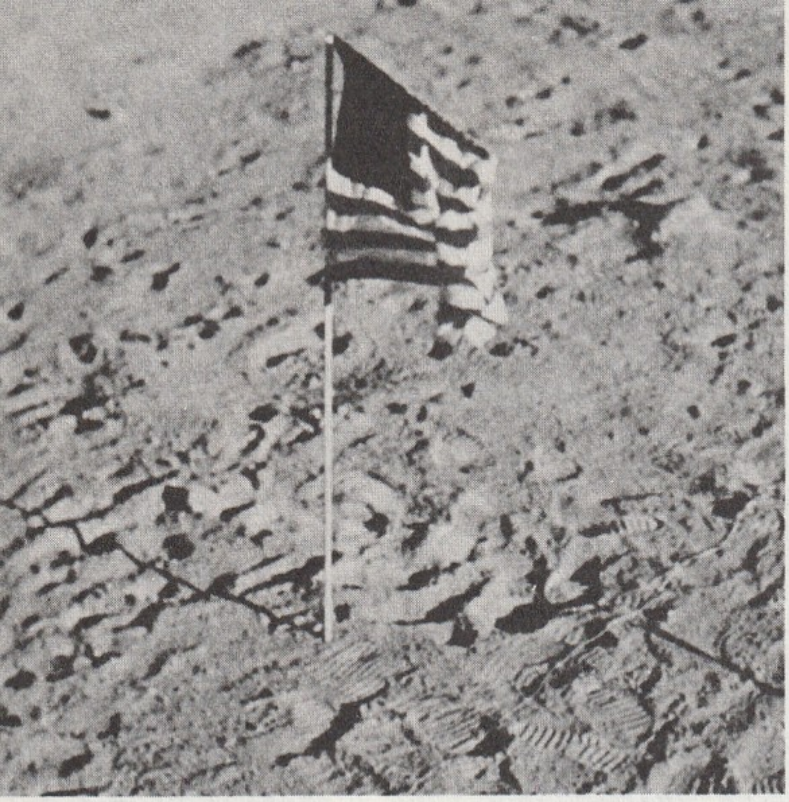


APPARENT SIZE AT PERIGEE

APPARENT SIZE AT APOGEE

The moon really does look larger on some nights —and for good reason; it is nearer. At perigee the moon is 221,593 miles away; at apogee it is 252,948 miles away. Its mean distance is 238,857 miles measured from the center of each.





The first flag of the United States on the moon's surface, in a photograph taken from inside Apollo 11. In the foreground the astronauts' footprints stand out clearly.

enough to seem large in comparison to other objects in the sky. In fact, the moon is the only heavenly body whose distance from the earth can be measured in mere thousands of miles. The moon, in short, has always been handy for viewing and for scientific investigation.

But it wasn't until this past decade that the moon was brought within the range of man's full ability to study it. It was the development of the rocket for space exploration that made this possible. Before rockets carried probes to the moon, and finally carried man himself, examination of the moon was limited to the unaided eye or to telescopes. The 200-inch telescope at Mount Palomar in California was able to bring craters to within an apparent distance of 200 miles. By contrast, American and Russian spacecraft were able to send back to earth thousands of photographic closeups of the moon, some from the surface itself.

Man in the 1960s probed the moon with almost fifty spacecraft, photographing it, poking and scratching its surface, measuring its temperatures, analyzing its chemistry. Then came the epic voyage of Apollo 11 in 1969, followed by landings and exploration by other teams of American astronauts in the ensuing three years. By descending to various regions of the moon and actually probing the lunar surface for hours on end, these men were able to check firsthand some of the theories that had developed over the ages. They brought home hundreds of pounds of precious lunar soil and rocks, set up scientific stations, and took photographs of the environment. The rocks became the object of intensive

laboratory analysis around the world. Scientists at last had firsthand evidence with which to work.

What Astronauts Found

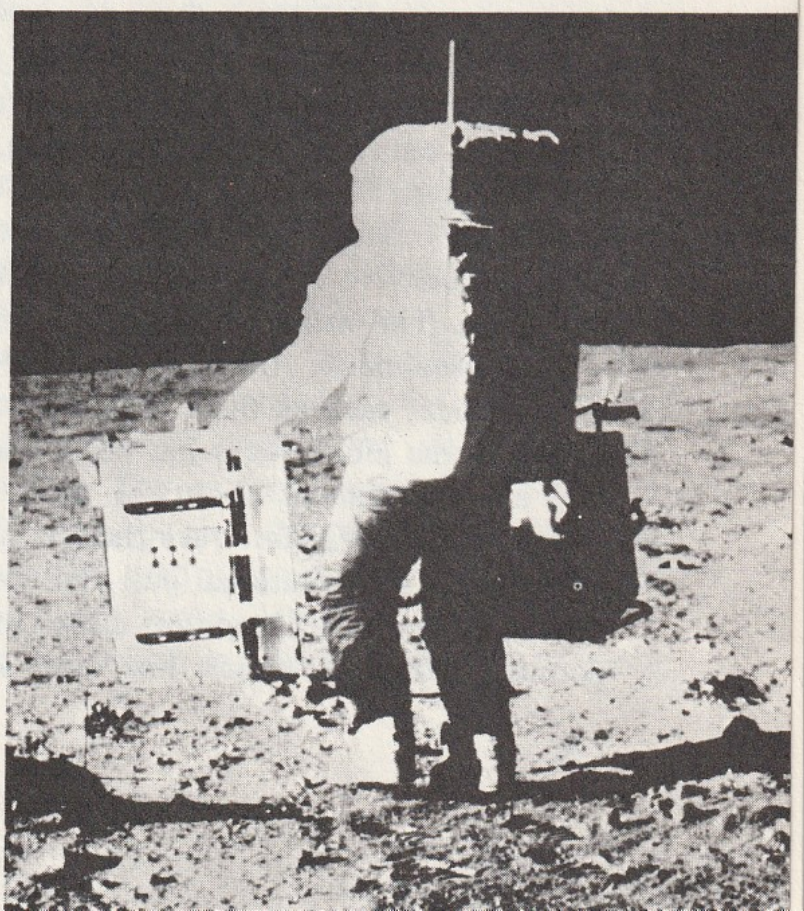
FROM THAT EVIDENCE emerged a broad portrait. For uncounted centuries men gazing with wonder at the moon have regarded it mostly as a cold, unchanging wasteland. The Apollo missions gave striking evidence that the moon is, indeed, a wasteland, and probably always has been. But it now seems probable that the moon was not always cold—or unchanging.

The early history of the moon, in fact, may have been extremely violent—a seething, molten mass, pocked by erupting volcanoes, spread with fiery "seas" and shuddering under the impact of meteorites.

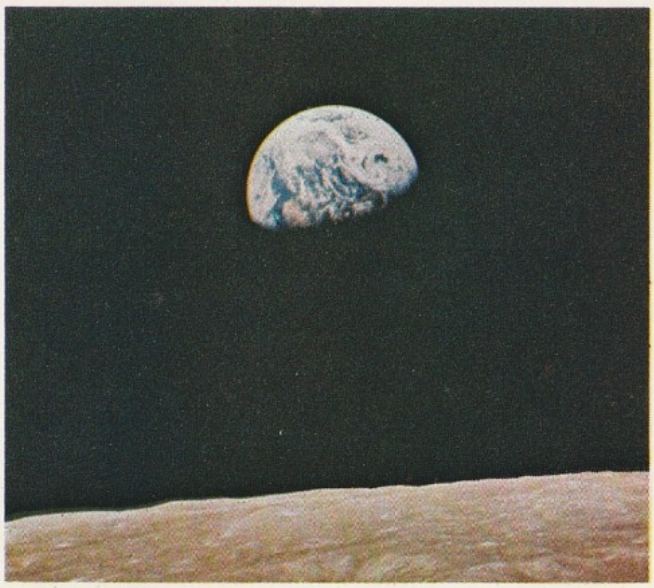
Out of the Apollo expeditions, in addition to the broad portrait, came many interesting details about the moon. For example:

Life on the moon. No living organisms were found, not even of the most basic kind.

Water. Astronauts saw no signs of any, but some scientists report that instruments left on the moon have detected water vapor. The question is very much unsettled.



Astronaut Aldrin, "at work" on the moon's surface, prepares to set up two experiments during the first Apollo moon visit, in July, 1969.



In this magnificent photo, the moon is in the foreground, with the cloud-covered earth a quarter-million miles in the distance. The view of the rising earth greeted the Apollo 8 astronauts as they came from behind the moon during an orbit at Christmastime, 1968.

2. THE EARTH AND THE MOON

Age of moon. The ages of virtually all lunar rocks brought home seem to lie between 3.2 and 4.1 billion years, although most scientists still believe the moon dates back to the beginning of the solar system about 4.6 billion years ago.

Rocks. Three basic kinds were found, in contrast to several hundred different types on earth: a basalt; an aluminum-rich anorthosite; and a radioactive rock christened kreep. Many were igneous—meaning they were once molten, formed either by volcanic action or by meteoritic impact.

Precious metals. No traces of gold, silver or the like.

Lunar crust. There is one, lying approximately thirty-eight miles thick across the entire surface of the moon. The crust formed when lightweight minerals floated to the surface, during a time the outside of the moon was molten, and later solidified.

Volcanoes. No one is yet sure whether there are active volcanoes on the moon. The astronauts found none.

Inside the moon. Although most experts believe there is no iron core in the moon, such as there is in the earth, the presence of faint magnetism in the moon rocks has been discovered, suggesting otherwise. A real mystery remains about the moon's interior.

Moonquakes. Quakes rack the moon but are very, very small, caused by the earth's gravitational pull and not by the stress of internal forces.

Moon's surface. Atop the crust, mostly pulverized lava is found, pounded very fine, almost like dust. In some places this dust is fifty

per cent glass—shiny little globes and teardrops. To one astronaut it seemed like "powdered charcoal". In some places, astronaut boots sank in only a quarter of an inch; in others, almost a foot.

Some of these findings are elaborated on elsewhere in this story of the moon. They are thrilling to scientists, but have raised almost as many questions as they have answered. There still is no positive information telling how the moon was created, where it came from, exactly how its features were formed, or precisely what the moon is made of.

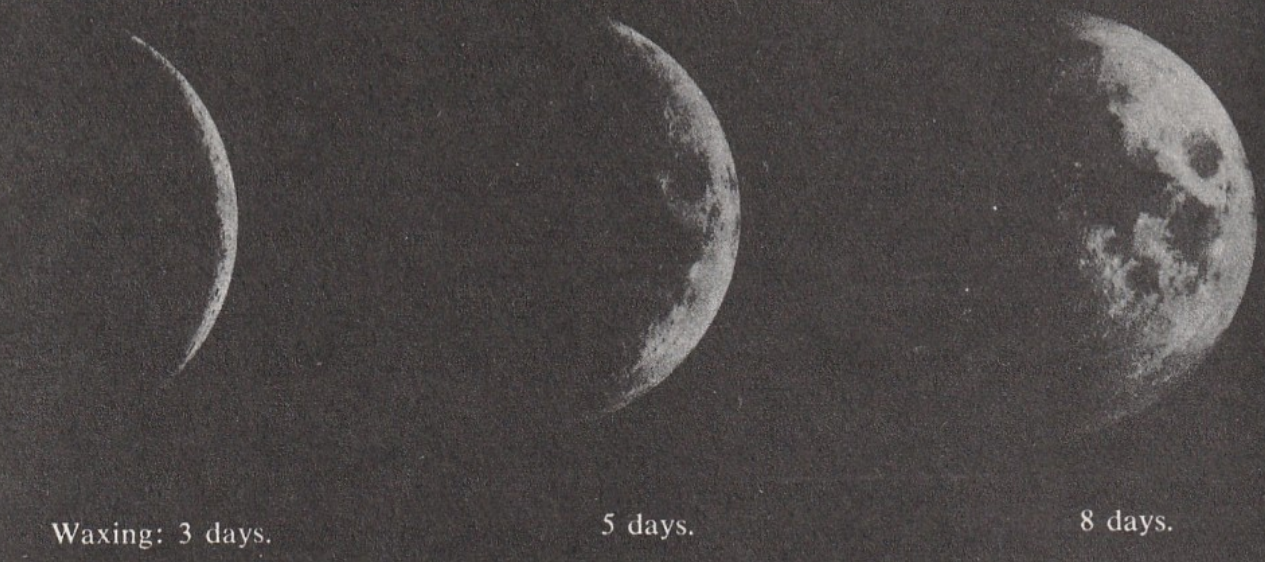
Puzzles such as those, scientists hope, will be solved inside the coming decade, as the mountain of data from Project Apollo is analyzed and theories are tested. In the meantime, it can be entertaining and also rewarding to consider what we do know about our nearest celestial neighbor, and try to imagine what some of the final answers may be.

To start, we must go back many centuries in time.

Early Moongazers

THE MOON was the first thing Galileo looked at in 1609 when he built his telescope, which he called his "optik tube", but the history of moon-watching goes back much further than that. In fact, the moon was involved in a very early recorded astronomical occurrence: one day

Close-up view of an astronaut's boot and footprint in lunar soil, photographed with a 70 mm. camera during the Apollo 11 mission.



Waxing: 3 days. 5 days. 8 days.

11 days. 14 days. 17 days.

Waning: 20 days. 23 days. 26 days.

in 2137 B.C., the Chinese saw the moon get in the way of the sun (a solar eclipse), and they entered the observation in their histories. Not long after, the Egyptians and East Indians started recording their observations. The Chaldeans were known to have kept very good records of lunar movements—especially eclipses—as early as 1000 B.C. In early times the Greeks also were active in scientific study of the moon.

Primitive man, living so close to nature, must have been impressed first of all by the recurring rhythm of the rising and setting sun. Thus it was natural to count the passing time in days.

In the night sky, the most conspicuous object is the moon. The moon, unlike other heavenly objects, conspicuously changes its appearance from the delicate crescent of the new moon to first quarter, then to the brilliant round orb of the full moon, and finally the last quarter before its disappearance from the sky for a few nights. It would soon be obvious to any watcher of the sky that there is a rhythm to these changes. So it was natural to mark the passage of longer intervals of time in "moons".

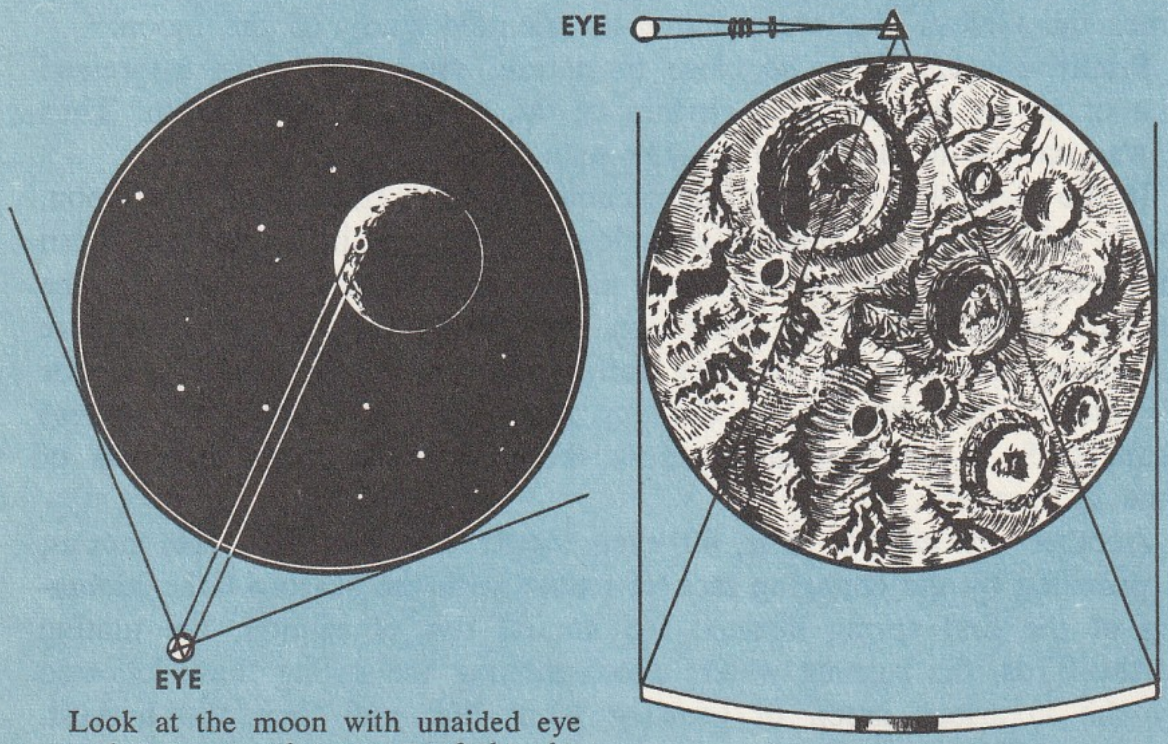
Another measure of time, in even longer intervals than the moons, is provided by the changing face of nature with the seasons—the blooming of the first spring flowers, the annual run of salmon, the mating of the birds, the rushing waters accompanying the spring thaw followed by the luxurious green of growing plant life, and then the harvest.

These incidents, so important in the daily life of a primitive people, served to mark the passing years.

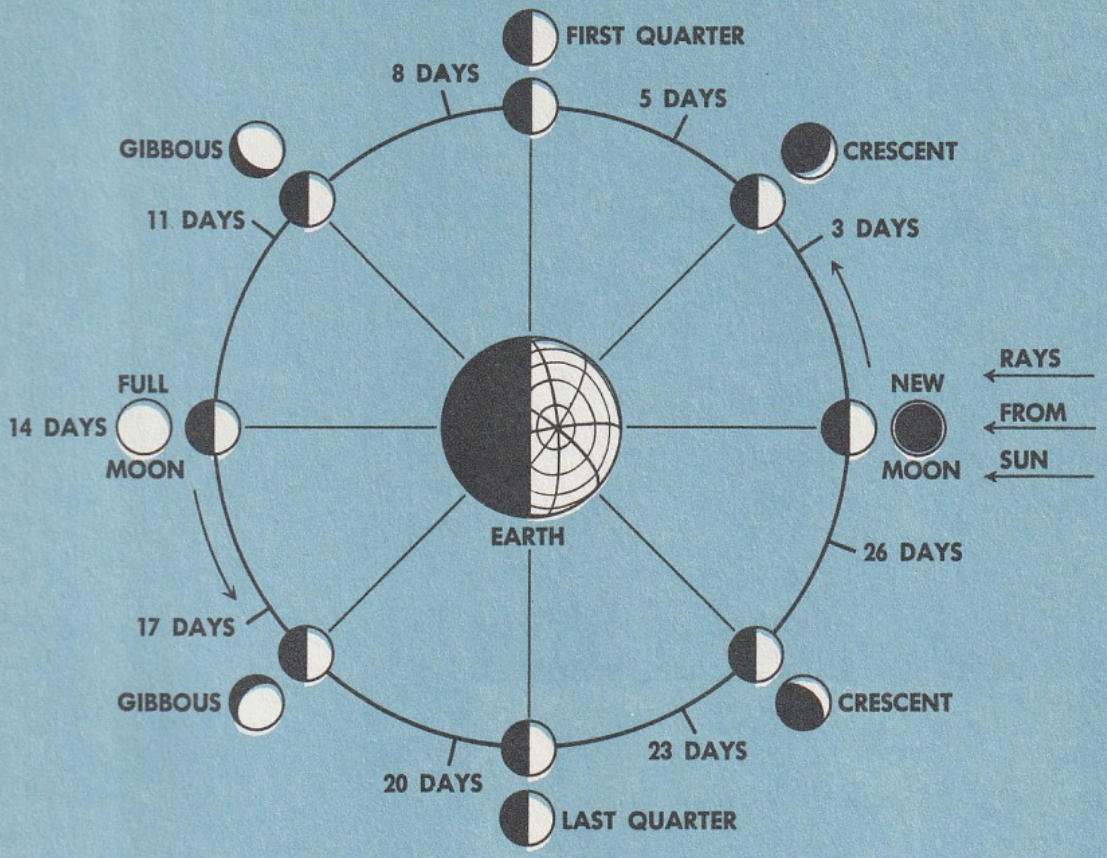
But there never was any harmony between the year, as marked by recurring signs of spring, and any particular number of lunar months. As a result, many astronomers tried to improve the calendar by studying the lunar cycle.

A Flow of Knowledge

IN THE MEANTIME, men were absorbing a great deal about the moon itself. Men learned what causes eclipses, calculated the moon's orbit and measured its distance from earth by triangulation, the same means surveyors use to measure distance in laying out tracts of land. Today, modern measurements of the moon's distance are achieved by reflecting radar signals off it or, in the case of experiments set up on the moon by Apollo astronauts, bouncing powerful laser beams off an eighteen-inch reflector set up on the lunar surface. Scientists at Lick Observatory, Mount Hamilton, California, have been able to establish, through the use of laser bounces, measurements of the distance to the moon that are precise to within six inches.



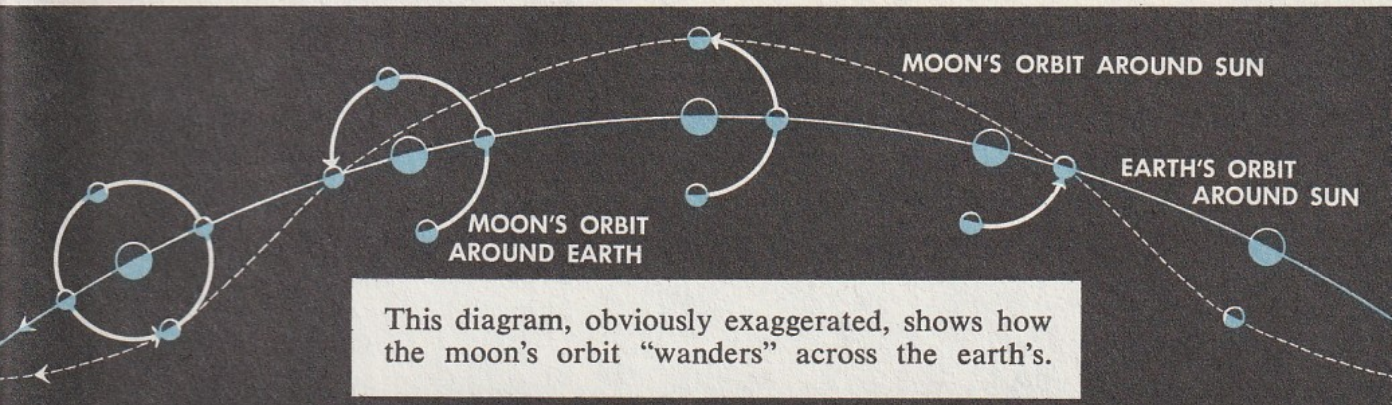
Look at the moon with unaided eye and you see a large part of the sky as well. A telescope looks only at a small portion which is then magnified by a series of prisms and lenses.



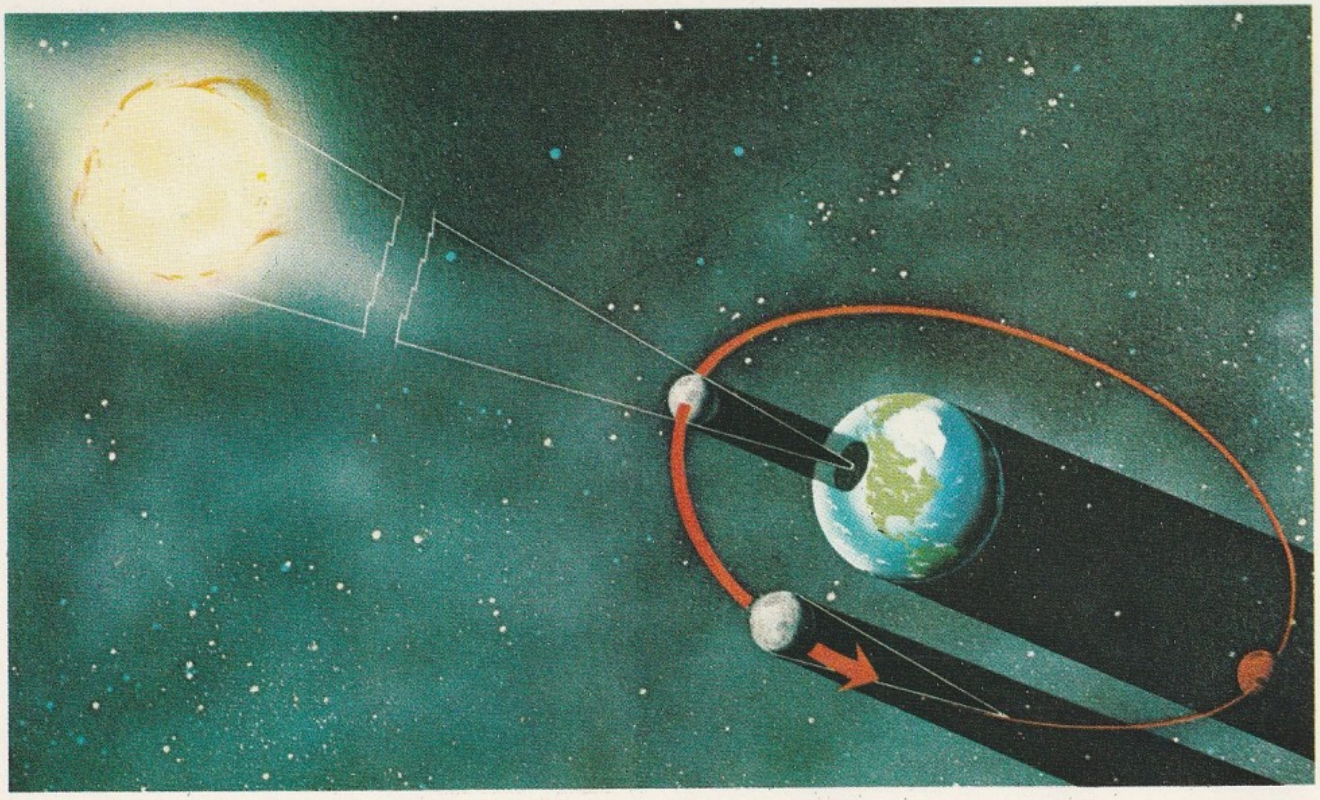
Half the moon is always lighted by the sun (shown by the inner ring of moons). From earth we see only the lighted portion of the moon (shown by the outer circle) as it turns in its orbit.

Men of bygone years figured out that they were prevented from seeing more than one lunar face because the moon rotates on its axis once every revolution about the earth. They also believed that the moon was made of material very much like that which constitutes the earth.

A long time, more than 2,000 years, went by before anyone actually saw the moon's features clearly enough to distinguish among them. Galileo was the first in 1609. Although his "optik tube" was not much better than one of today's inexpensive spy-glasses, it did permit the astronomer to see many craters, walled plains, mountains and the im-



This diagram, obviously exaggerated, shows how the moon's orbit "wanders" across the earth's.



1. A DIAGRAM OF A SOLAR ECLIPSE

When the moon's orbit brings it between the sun and the earth, we are in the moon's shadow. We call this a solar eclipse. When the moon passes behind the earth and away from the sun, it is in the earth's shadow, and a lunar eclipse takes place.

mense lava flows that he called "maria" because they looked so much like seas. In addition, Galileo observed the moon's "librations" or apparent wobblings that allow us to peek over the edges of the moon and see a little more than half of the lunar surface. And Galileo calculated mountain heights on the moon by measuring the length of shadows.

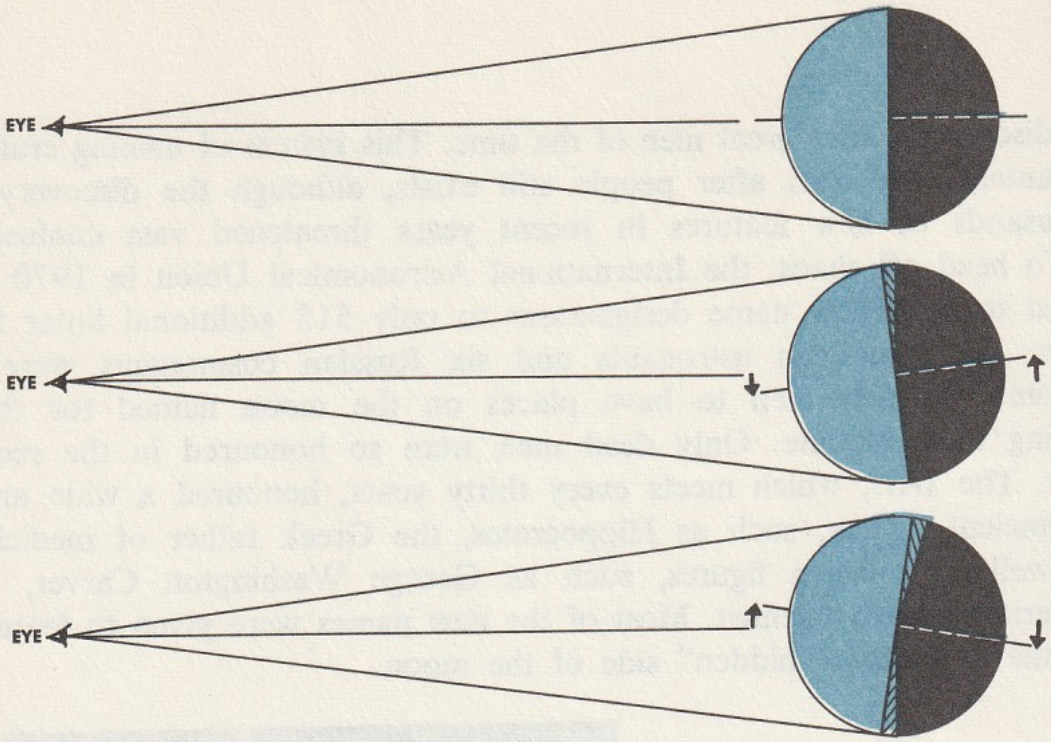
How Moon Features Get Their Names

NOT LONG AFTER 1610, when Galileo published his book about the moon, including the first rough map of the lunar surface, other astronomers turned telescopes toward the great yellowish orb. Hevelius of Danzig published the first really good map of the moon in 1647. He described some 250 features and named them after similar formations on earth. Some of those names—Apennines, Caucasus, Alps—are still used, but that method of naming moon features was changed four years later by an Italian astronomer, Riccioli. He chose to name the features

he discovered after great men of the time. This system of naming craters, mountains and seas after people still exists, although the discovery of thousands of new features in recent years threatened vast confusion.

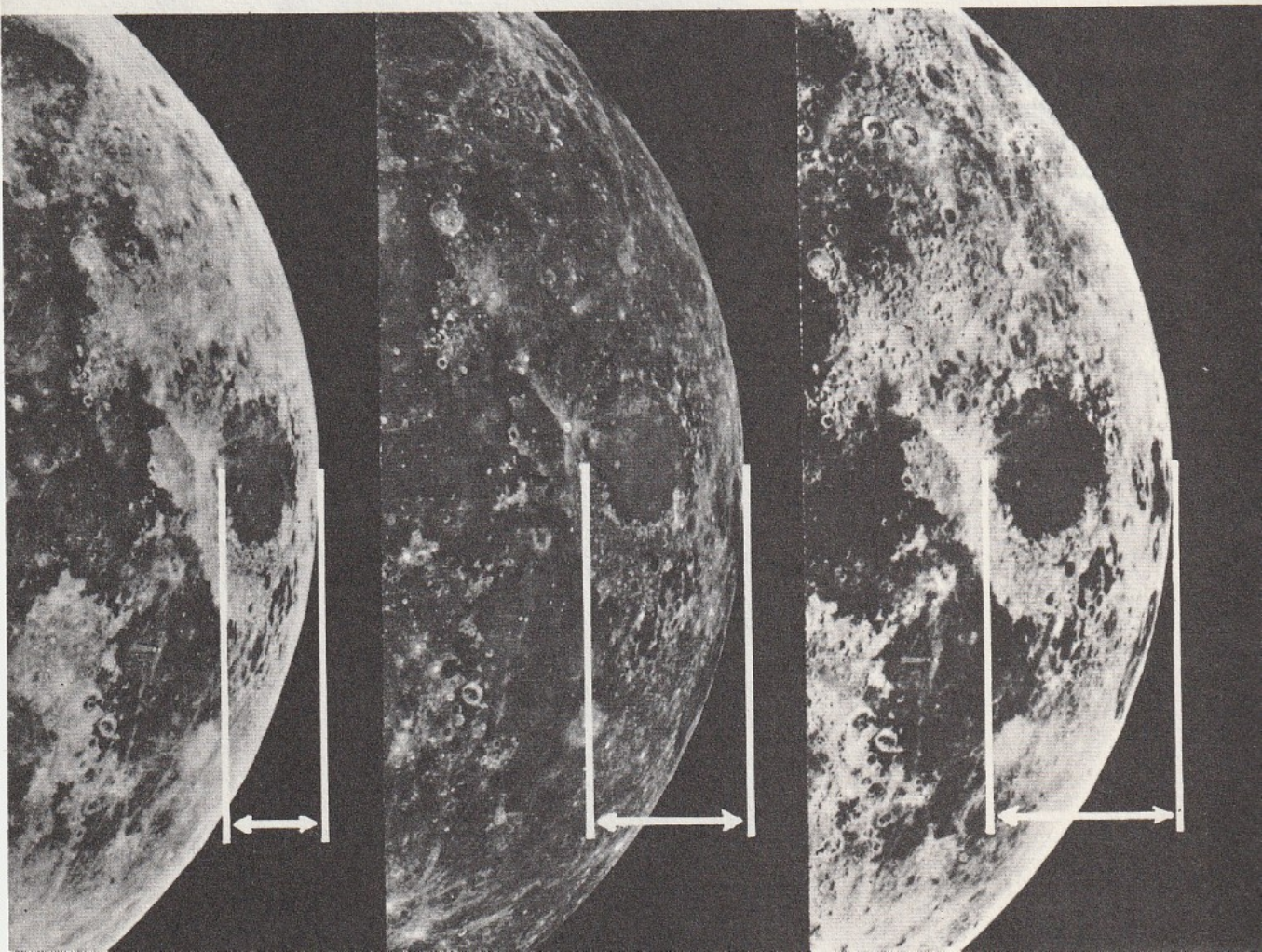
To head off chaos, the International Astronomical Union in 1970 decided to limit new name designations to only 513 additional lunar features. Six American astronauts and six Russian cosmonauts were to become the first men to have places on the moon named for them during their lifetime. Only dead men were so honoured in the recent past. The IAU, which meets every thirty years, honoured a wide array of ancient figures, such as Hippocrates, the Greek father of medicine, as well as modern figures, such as George Washington Carver, the American Negro scientist. Most of the new names were given to features on the heretofore "hidden" side of the moon.

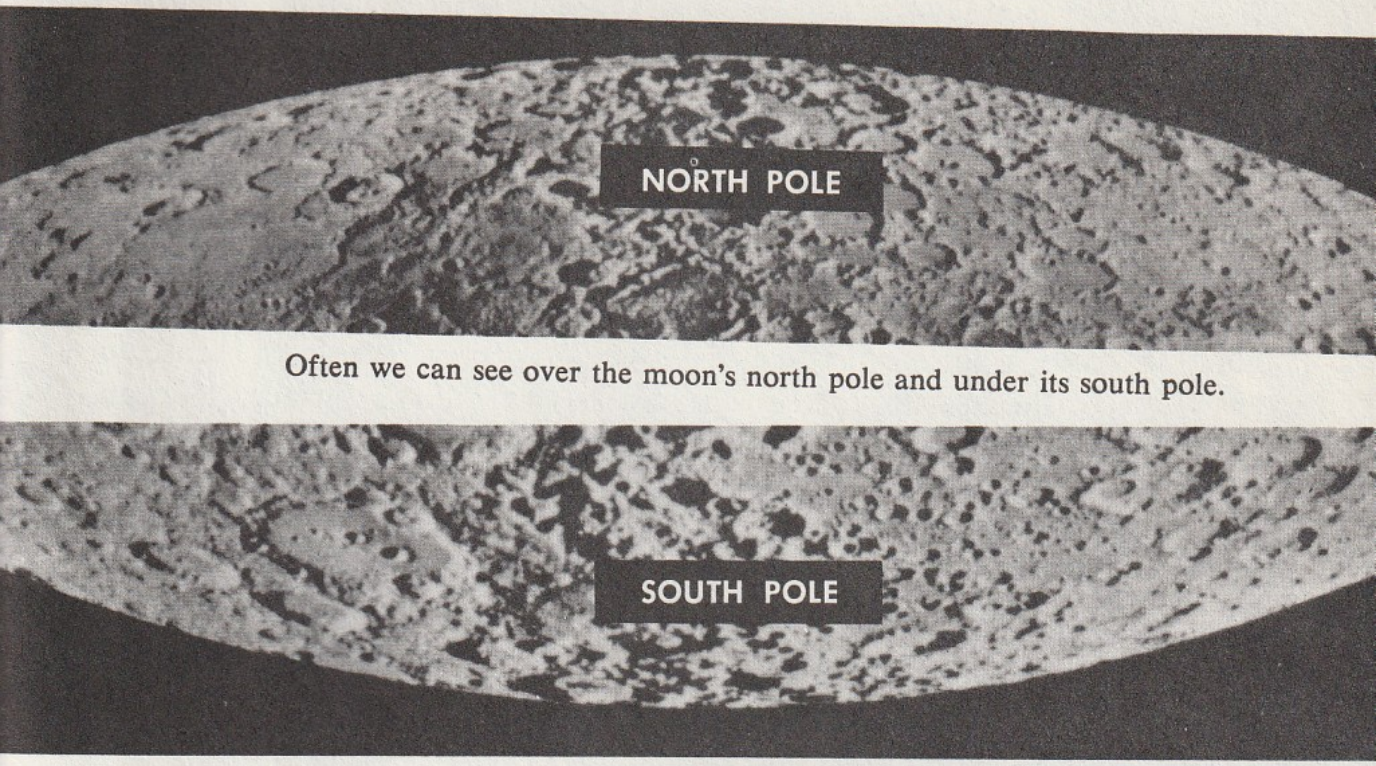
The floor of the moon's crater Copernicus and the area to its south are shown in unusual detail in this photograph taken by Lunar Orbiter II. The mountains rising from the flat floor of the crater are about 1,000 feet high, and the distance from the horizon to the base of the photograph is about 180 miles.



Top: We can always see at least half of the full moon.
Center: When the moon tips forward we see over its north pole.
Bottom: When the moon tips backward we see under the south pole.

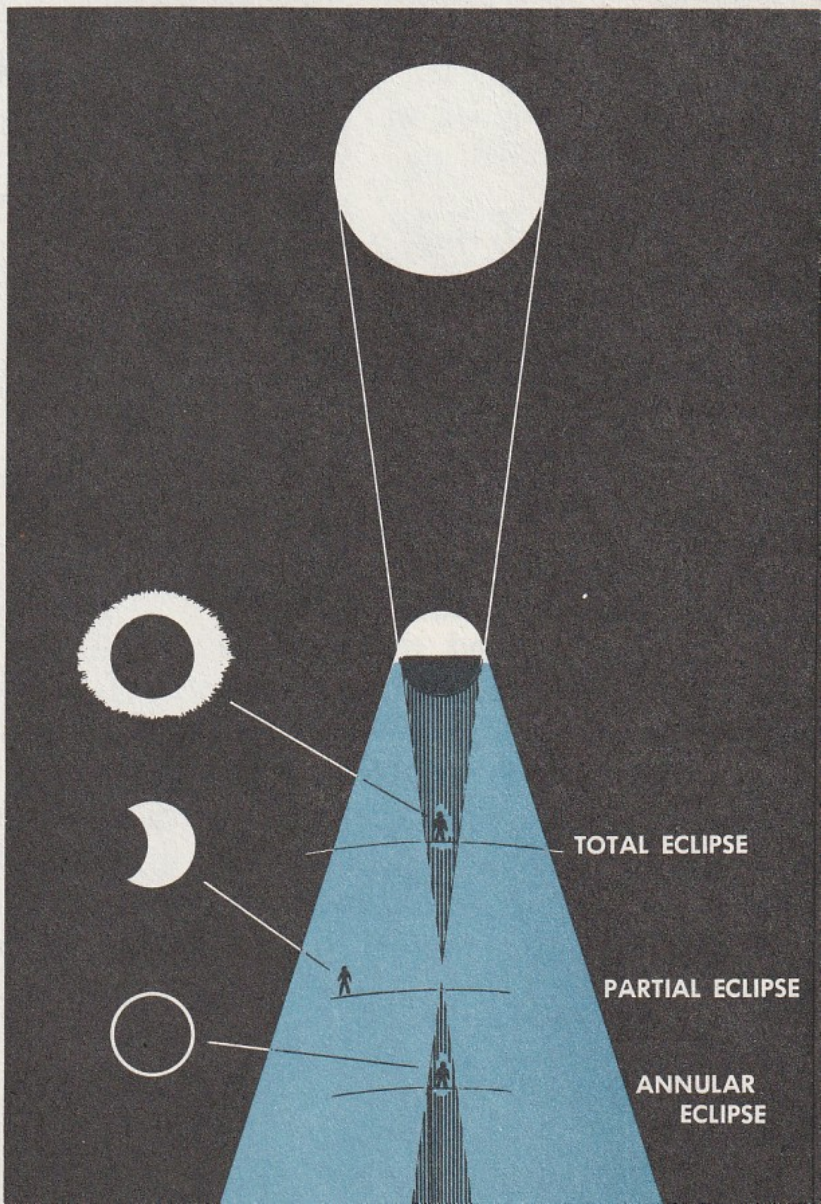
In these photographs it is obvious that the moon wobbles sideways, as well as forward. Altogether, therefore, we are able to see fifty-nine per cent of the moon's surface.





Often we can see over the moon's north pole and under its south pole.

The type of solar eclipse we see depends on the moon's distance from the earth. When the moon is nearest it covers the sun completely, allowing us to see its corona. Further away we see only a partial eclipse; while at its furthest position the moon appears smaller than the sun and we see an annular eclipse —a white ring.



Early Studies

FOR THE FIRST HUNDRED YEARS of the telescope, astronomers spent most of their time simply describing the moon without trying to answer questions about its nature and history. Some scientists, such as Sir Isaac Newton and Johannes Kepler, studied the way the moon moved across the heavens, but it was not until later that anyone tried to study activity on the moon's surface. A German astronomer named J. S. Schroeter was one of the first to suspect changes on the moon's surface. He published his findings in 1791. In his book, he said he believed he had seen movements, such as mists in the bottoms of craters, or alterations in the shapes of other structures. He attributed those changes to a very thin lunar atmosphere and to volcanic action. Observations such as his are occasionally reported even today, but many authorities feel that most such sightings from earth are probably optical illusions—the effects of changing illumination over the moon's surface, and distortions caused by the earth's atmosphere.

Herr Schroeter's book aroused new interest in the moon, and lunar studies proceeded at a great rate for about forty years. Then a book about the moon was published in 1837 which was so very excellent that it is still quoted as authoritative. That book, called simply *Der Mond* (The Moon), was the result of seven years' work by two German astronomers, Beer and Maedler. In it they gave the diameters of 148 craters, the heights of 830 mountains and crater walls, the names of 150 new formations and enough other information about the moon to convince astronomers of that day that most of the important questions had been answered.

Superstition and Fantasy

BEER AND MAEDLER BELIEVED, as other astronomers long before them had, that the moon was a barren and dead world, completely incapable of supporting any form of life. Still, a good deal of excitement had been created—even in scientific circles—by a series of articles that appeared in the New York *Sun* beginning 21 August, 1835.

Those articles—written by Richard Adams Locke—were complete fabrication, yet they had an air of authenticity which would have made any of today's science fiction writers envious. Locke wrote of how Sir John Herschel, a noted astronomer, had made "some astronomical sightings of wonderful description" with a new telescope at the Cape of

This remarkable photograph of an annular eclipse was taken from an aircraft at 14,200 feet and shows clearly the moon almost covering the sun except for a white ring, all that is left of the sun.

One of the Locke Moon Hoax illustrations, which tried to show that there was plenty of life—and water—on the moon.

Good Hope on the southern tip of Africa. The instrument was said to magnify objects 40,000 times, making it possible (according to Locke) to see an object on the moon only eighteen inches wide. Locke described in fantastic detail amethyst moon mountains, sapphire hills and ruby temples at which bat-winged ape-men worshipped. Bison-like animals with flaps over their eyes to protect their vision from the intense sunlight mingled with goat-headed, one-horned, bearded beasts with long tails. Horned bears menaced two-legged beavers that carried their young in their arms like humans and built fires. In his article, Locke called the moon people "lunarians", but reported that Sir John dubbed them with the scientific name of "Vespertilio-homo" or man-bat. They were said to spend most of their time leaping and flying about, apparently "talking" to one another and gesticulating wildly.

The *Sun* articles were probably the wildest scientific hoax of all time and unquestionably one of the most successful. The paper's circulation soared, and even though Sir John Herschel denied indignantly that there was one scrap of truth to the stories, readers—many of them scientists—believed every word. In fact, a whole year passed before the hoax was exposed.

Moon Frogs: More Fiction

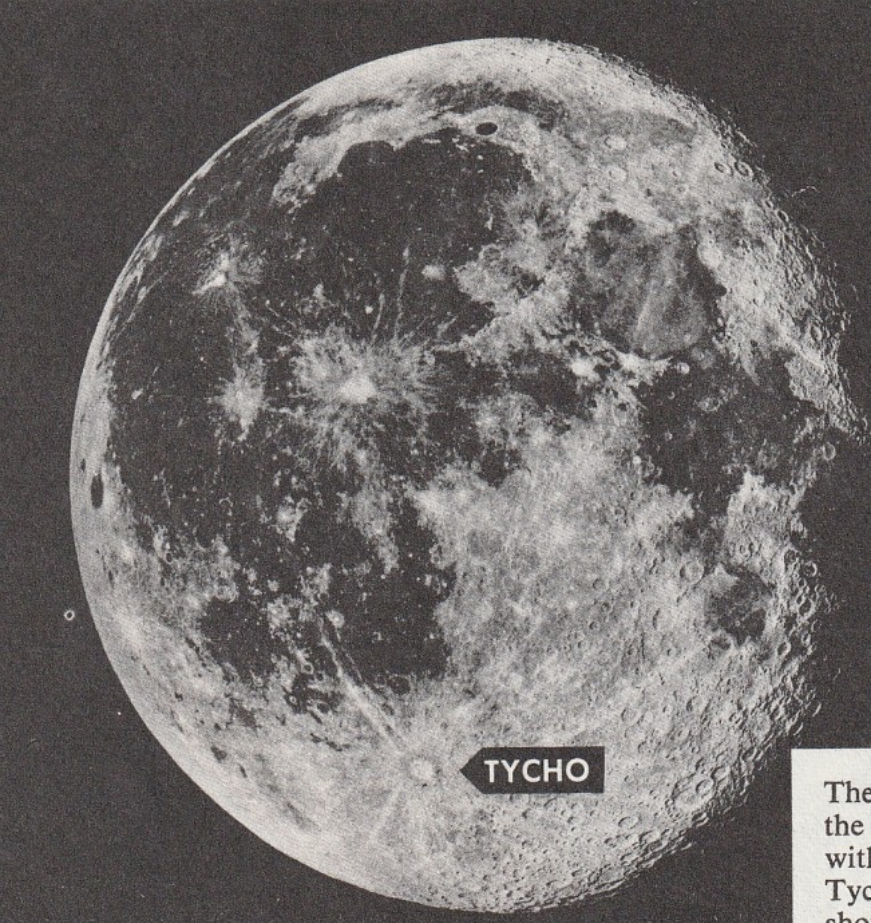
THE FAMOUS "LOCKE MOON HOAX" was not by any means the first fiction that peopled the moon with strange creatures. Most of the others were purely fictional accounts of men who said they had been to the moon and returned with reports of weird and wonderful things there.

Lucian of Samosata in the second century A.D. was the first to "go". In fact, he was the very first space fiction writer in classic literature. Lucian wrote two stories about trips to the moon. In one entitled *Icaromenippus,* he told of flying to the moon with one wing of an eagle and one of a vulture and finding spirits there which had departed from earth. The second trip, described in a volume entitled *A True Story,* was far more rich in adventure. In that fanciful account, Lucian got to the moon in a sailing ship borne on a waterspout and the wind. He "found" the moon cultivated and inhabited with strange beings called "Moonites". They were much larger than we, completely hairless except for a beard that reached to just above the knee, and they could pluck out their eyes—presumably to make it easier to see around corners. They ate and drank only sparingly, living entirely on fumes from the roasting of frogs that flew about in great numbers. They drank water which was squeezed from the air and melted from hailstones that grew on vines. Their diet made stomachs unnecessary, and instead, Moonites had hairy pouches in which to carry their valuables. There was so little substance to their food and drink that when a Moonite died he went up in smoke.

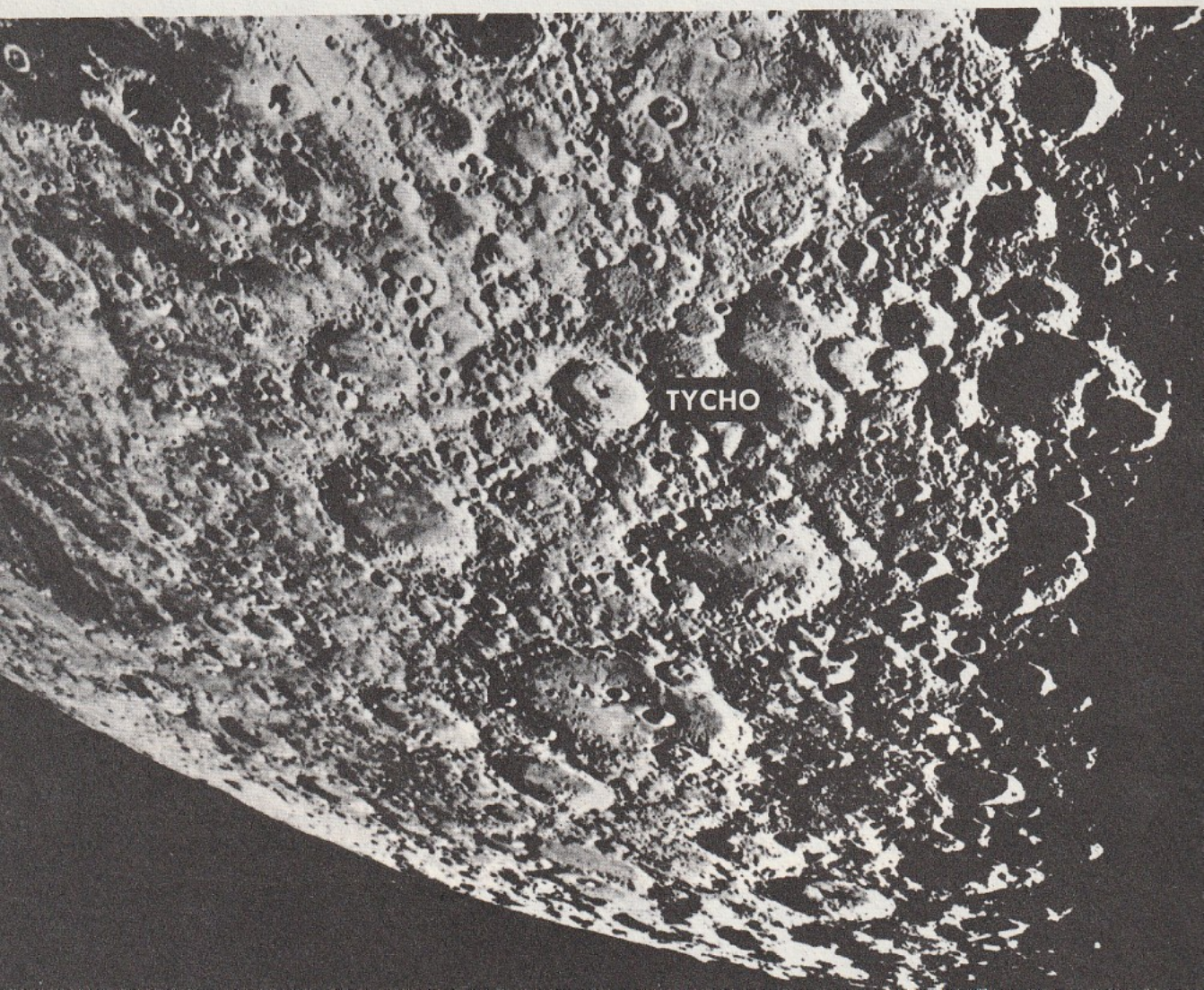
Still More Fantasy

THE FIRST NARRATIVE of a trip to the moon written in English was published in 1638. It was a book called *The Man in the Moone* by Bishop Francis Godwin. Bishop Godwin's narrator, Domingo Gonsales, took him all the way to the moon. During the twelve-day "trip", Gonsales trained a flock of birds to fly at his command and carry him wherever he wanted to go. During one such flight, the birds got out of hand and described the feeling of diminishing gravitation—remarkably, more than a half-century before Newton conceived the theory of gravitational attraction. Gonsales, then, was the first man to contend with the state of "weightlessness", something that confronts space fliers. Gonsales "found" the moon mostly ocean, and what little land there was, was inhabited by people he called "Lunars". They were much like us except that they were twice as tall and could travel great distances by leaping into the air and

This multiple exposure photograph of a partial lunar eclipse was taken over New York City. As the moon rose in the east and travelled westward across the sky, so it moved out of the earth's shadow. *Top right:* Although the earth's shadow covers more than half the moon, the dark area is still illuminated either by earthshine (light reflected from the earth's surface) or by refracted sunlight (light that is bent when passing through the earth's atmosphere). A lunar eclipse is more frequent, but less spectacular, than a solar eclipse.



The most obvious feature on the moon, and most easily seen with the naked eye, is the crater Tycho and its huge ray system, shown in detail below.



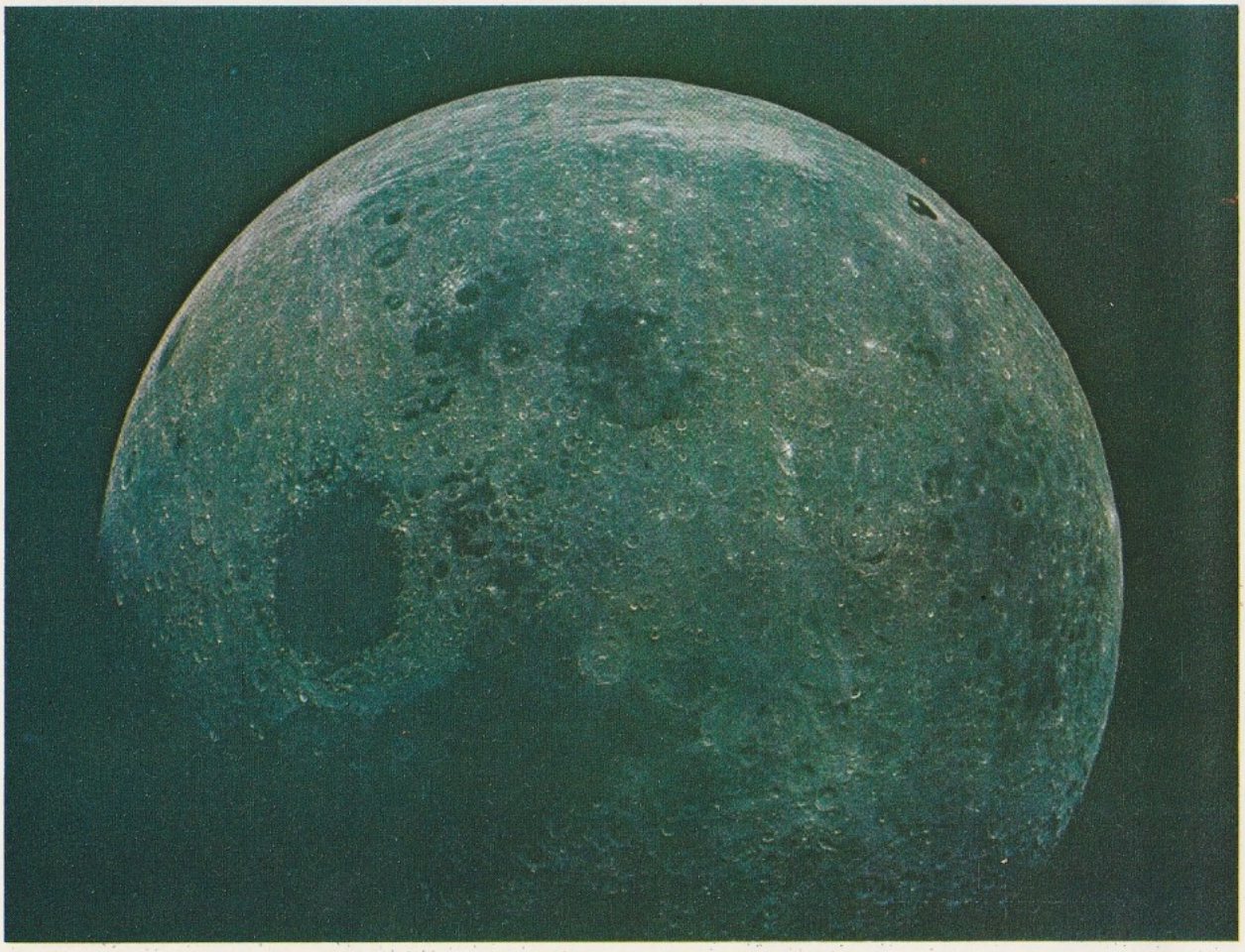
fanning themselves along. They spoke in song, and smoked incessantly, but otherwise were "perfectly normal".

After that tale, the literature became really congested with fanciful yarns about trips to the moon. It seems as though each writer tried to outdo those before him in dreaming up peculiarities for their imagined moon inhabitants. Cyrano de Bergerac—the man himself, whose name became immortalized in the play by Rostand—told how he had encountered four-legged "Lunarians" who shot at birds with a device that killed, plucked, roasted and seasoned them all at once. Another writer, who used the pen name "Aratus", wrote of flying a balloon to the moon in "17 days, 6 hours, 2 minutes, and 3 seconds", landing on an island that resembled England, and discovering creatures called "selenites", which looked like snakes except that they walked upright and spoke English. H. G. Wells in 1901 described his "selenites" (from the Greek moon goddess, Selene) as insect men of various shapes and sizes, each of whom had a special task for which he had been developed, worked at his own job and enjoyed nothing else.

The Man in the Moon

OF COURSE, all of those stories have nothing to do with the fictitious Man in the Moon, himself.

Who is he? According to the German folk version, he is a stealer of



6. THE MOON FROM APOLLO 8

This photo of a nearly full moon was taken from the Apollo 8 spacecraft. Mare Crisium, the circular, dark-colored area near the center, is near the eastern edge of the moon when viewed from earth.

cabbages who was put there for punishment and as an example to anyone who might think such a diversion profitable. On the island of Sylt, he is a sheep stealer. In Polynesia he is just a common thief. And in some places—in Greek and Romanian folklore, for example—he is not a man at all but a woman: the sun's sister, the Lady of the Night.

Whoever the Man (or Woman) in the Moon may be, superstitious people have long believed that he exerts a powerful influence over events on earth. For example, people once thought that everything on earth waxed and waned with the phases of the moon, which influenced crops, fish and game, marriage, money, birth and death. Even today, some persons refuse to sow grain or cut trees when the moon is new.

Strongest of all, however, is the idea that the moon can affect a person's actions (origin of the word "lunatic"). If such an influence does exist, scientists have been unable to demonstrate it in the laboratory, and until this is done, it is perhaps best to conclude that the only effect that the moon has on human activity is in the realm of romance.

Origin of the Moon

THERE IS ONE FANCY that people have had about the moon which stands up quite well, according to what we know today. In medieval times, people believed that the moon was a gigantic mirror hanging in the heavens, and that the dark markings on it were nothing more than reflections of the earth's features. Although we certainly know better now, there is an element of truth in that notion, for the moon does, indeed, "reflect" the earth's mountains and valleys—but as they probably existed here billions of years ago. In fact, if it were not for the earth's protective (and erosive) atmosphere and the waters that wear away the land—neither of which affects the moon's surface—the earth and moon would probably look very much alike.

In a sense, then, the moon may be considered to be a "fossil earth". Studies of the moon in this respect can be as helpful in learning more about the early stages of the solar system's development as studies of plant and animal fossils are in finding out how life developed on earth.

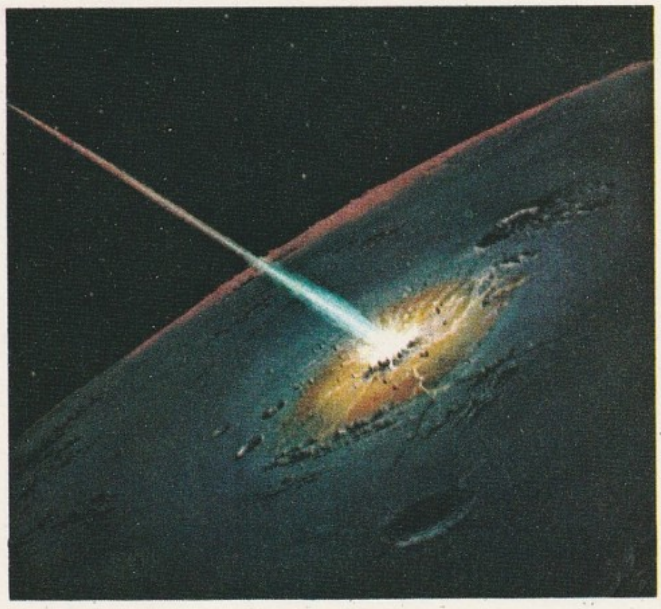
The moon's beginnings lie with the earth's, down the well of time, now estimated to be about 4.6 billion years deep. According to the latest estimates, both moon and earth were created that long ago.

Actually, there are three popular theories of how the moon may have been born. One theory is that the moon is a daughter of the earth, once part of our planet but somehow broken away from it. Another is that the moon was a small, separate planet wandering around the solar system before it was somehow captured into the earth's orbit. Finally, a third theory holds that the moon and earth are sister bodies, formed simultaneously as a double-planet system.

This third theory is the most popular. It suggests that great masses of dust and gas were swirling through space, and one of these masses hardened into our solar system. About ninety-four per cent of that gigantic gaseous whirl condensed into our sun, leaving roughly six per cent behind in a flat, circular disc. The cloud of gas around the sun and in the great disc gradually drifted away, and the disc, consisting now of dust and larger fragments of cosmic rubble, rotated and broke up into

Looking at this snakelike rille within the seventy-five-mile-long Alpine Valley one might wonder whether it could be a river channel. Some experts believe that rilles could have been carved by rivers if there was a period when the moon had a temporary atmosphere. This photograph was taken by Lunar Orbiter V from an altitude of 81.8 miles.

Some scientists believe the moon's craters were caused by huge meteors striking its thin crust millions of years ago, as shown in this artist's conception. The meteor's path is exaggerated.



4. A METEOR STRIKES

individual congestions of matter. Those were the "proto-planets". They pursued independent courses around the newborn sun, and soon each formed its own nucleus. In the orbit of the earth's proto-planet, two such nuclei were formed. The smaller one revolved around the larger as they both grew through the slow accumulation of dust and pieces of rock. It was probably in this manner that the earth and moon were born, and so are regarded by some authorities as a "double planet" rather than a planet-and-satellite system.

Although both bodies were formed cold, so to speak, the constant impacts of debris and the forces that made the earth and moon contract caused them to heat up. After several million years, both earth and moon were somewhat molten. When each has attained its present size, strong forces acting between the two bodies (which will be explained in greater detail later) forced the larger one to spin more slowly and the smaller one to move farther and farther away. During this phase of the moon's development its surface may have acquired its greatest scars.

Lunar Scars

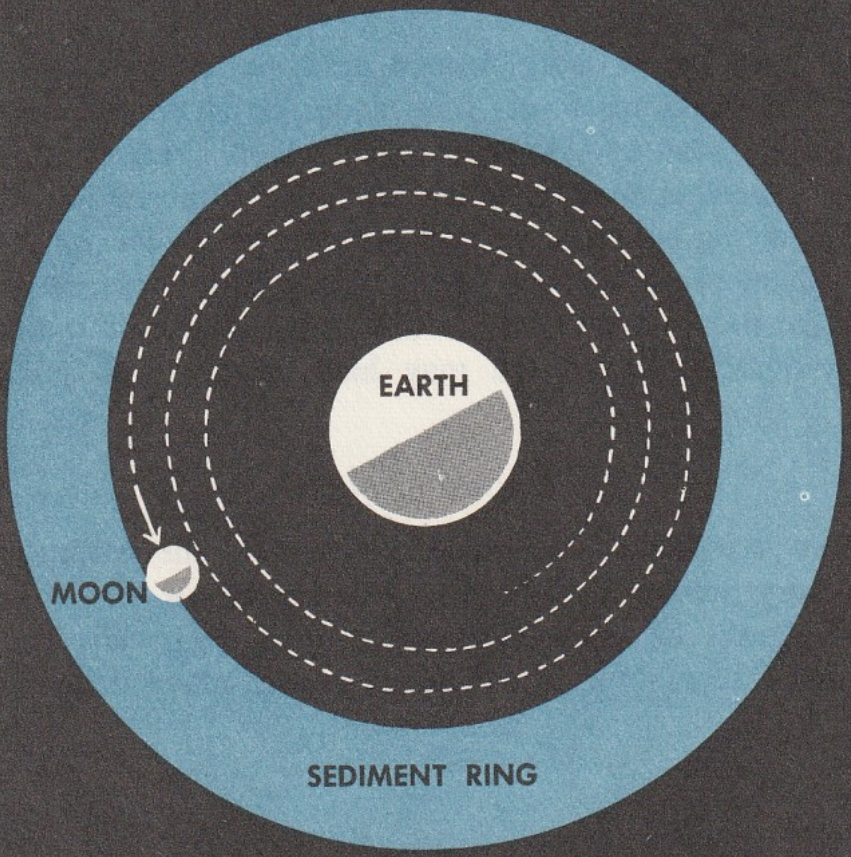
ACCORDING TO SOME LEADING ASTRONOMERS, the earth once had a ring very similar to Saturn's. This "sediment ring" consisted of meteor-like chunks of debris, ranging in size from dust particles and snowball-sized fragments to mountainous masses many miles in diameter.

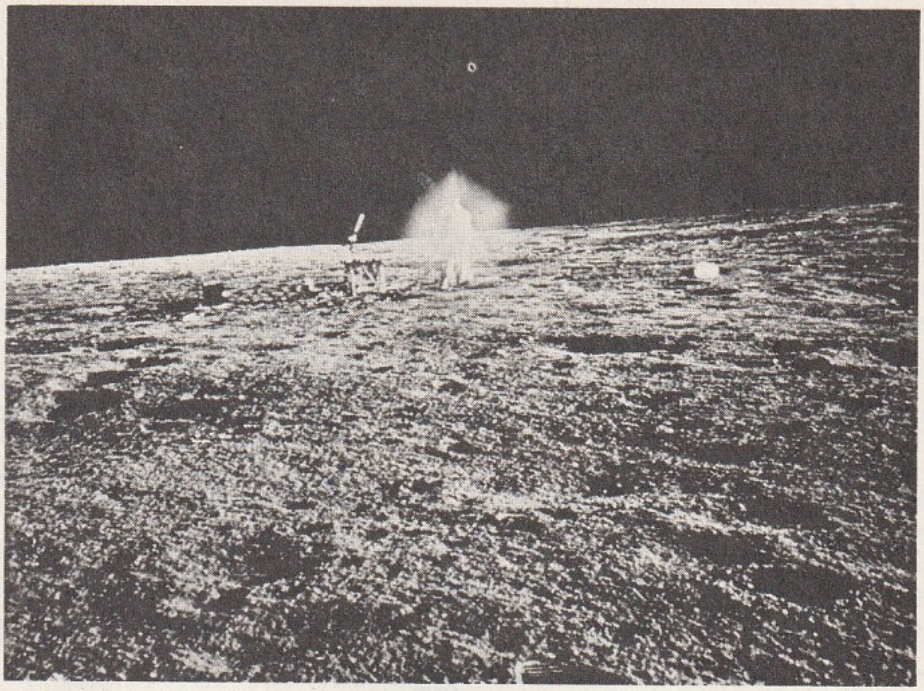
As the moon moved away from the earth, it passed through this sediment ring, sweeping it up within a period of from 100 million to 200 million years. And the moon has the scars to show for it.

Those scars are some of the oldest and biggest on the entire lunar surface. The crater Clavius, for example, is one such scar that was probably created during the movement of the moon through the earth's sediment ring. This scar is about 145 miles in diameter and makes the famous Meteor Crater in Arizona look like a posthole. To appreciate the violence that must have accompanied Clavius' creation, the event could be compared with a collision between the asteroid Hermes and the earth. If such a catastrophe were ever to take place, an area the size of Maine and New Hampshire would be completely devastated. Although such a thing is highly unlikely, it is nevertheless possible. In fact, the earth may have sustained such violent shocks in the past, though most of the resulting craters would have been lost eons ago in the seas, or erased by erosion.

Not long ago, scientists interested in the enormous difference between the number of craters on the moon and the number on earth set out on a

As the moon moved away from the earth, it "swept up" the sediment ring.





Apollo 12 astronaut is highlighted by an unexplained, ghostly flare as he scouts the Ocean of Storms, one of the moon's vast "seas".

crater hunt of world-wide proportions. The results of that study suggest that the earth is far more crater-scarred than had been believed previously. Thus, the earth may at one time have been very moonlike indeed.

"Seas" on the Moon

FROM THE ROCKS brought back to earth by Apollo astronauts, scientists have pieced together—although with some details missing and others the subject of debate—a story of the brief geologic life of the moon after its birth, including the story of how its so-called seas were created.

The moon, as the evidence shows, was born in a spasm of fiery violence, "lived" for perhaps a billion years in all, and then died, evolving no further, in contrast to the continuing evolution of earth. During its active life, as the moon formed a solid body, intense heat developed and turned it into a molten blob.

As the moon cooled, a crust formed. During this period the lunar surface was subjected to huge solid chunks of space debris, crashing into it and molding its features. Scientists believe that the heat created by these crashing bodies was intense enough to melt rock. This process, possibly aided by subsurface lava, led to the flooding of the vast lunar plains.

Immediately after a meteor has broken the moon's thin crust, hot molten lava wells up and spreads over the surrounding landscape. This may well account for the many "seas" visible on the moon.

5. THE MOON ERUPTS

One collision deserves special mention because it was probably the most violent event in the history of our solar system. So great, in fact, was the impact that not one but several maria, or seas, were created all at once. Out of this collision was born Mare Imbrium (the Sea of Showers). Its 340,000 square miles of hardened lava are more than enough to blanket both Britain and France. The lunar Alps may have been formed at the same time by blocks of rock many miles in diameter, which were displaced by the collision.

Both Apollo 11 and 12 landed on marias, and rocks brought home from both the Sea of Tranquility and the Ocean of Storms are basically of the same composition, indicating that all of the seas of the moon are filled with a similar type of rock, and probably from the same period—about 3.6 billion years ago. There is evidence that little has changed on the moon in the past 3.6 billion years except the continual battering by meteorites ripping in from space and carving out more craters. Because most of these meteorites are so small—and so common—they have caused a weathering of the rocks on the moon, accounting for the vast accumulation of dust—the shiny powder that clung to the astronauts as they went about their business on the moon.

Does all this make the moon sound barren and desolate? It didn't seem so to the Americans who were there. Said a member of the Apollo 15 crew: "I hesitate to use the words barren and desolate, because I think to the three of us the moon is dynamic, it is beautiful and it has character."

Science Bulletin
Prepared by SCIENCE SERVICE

AN "OUT OF WHACK" MOON

The moon looks spherical to us on the earth, but actually it is not a completely symmetrical globe.

The average radius of the moon is 1,737 kilometers, but at only two places does the moon have this radius.

The near side of the moon averages two kilometers less and the far side from six to nine kilometers more than the average or mean radius.

Now scientists studying results obtained by a laser altimeter have some new facts. W. M. Kaula and Gerald Schubert of the University of California at Los Angeles and W. L. Sjogren of the Jet Propulsion Laboratory in Pasadena report that they have detected certain features on the moon's surface that help account for the moon's lopsidedness.

There is a large (1,400-kilometer-wide) unfilled basin on the far side at 180 degrees longitude. "This basin and the low mare at the near side with the highlands sticking out on the sides account for the distorted shape," says Schubert.

MOON IMPACT

For two years, scientists had been waiting for a meteorite impact on the moon large enough to be detected at more than one of the Apollo Lunar Surface Experiments Package (ALSEP) stations left behind by Apollo astronauts.

Seismic data from such an impact could be used to determine the material deep in the lunar interior. That impact finally came at 3:49 A.M. CDT, 13 May,

1972, and all four seismometers that have been set up at the landing sites recorded the impact.

Gary Latham of the Lamont-Doherty Geological Observatory, principal investigator for the instruments, says the impact was equivalent to 1,000 tons of TNT, one hundred times larger than the impacts of the Saturn S4-B's that have been used to calibrate seismic signals.

The meteorite hit "uncomfortably close" to the Apollo 14 ALSEP station and formed a new football-field-sized crater. The seismic instrument at 14 went "off scale" high from the impact and remained that way until ground control sent a signal to the instrument to reduce its sensitivity.

AN EARTH TWIN FOR A MOON ROCK

Geologists hope to unravel the earth's early history by exploration of the moon and its composition. Although the moon rocks returned so far are composed of the same common elements as are earth rocks, there are differences in the amounts of the elements contained in them and their chemical state.

One example is the anorthosites. Anorthosites are plutonic rocks (crystalline rocks formed from molten material) made up primarily of plagioclase, a common mineral composed of aluminum silicates of potassium, sodium and calcium.

On earth most of the plagioclase is rich in sodium, while the plagioclase in the anorthosite returned from the moon by Apollo 15 (dubbed the Genesis Rock) is rich in calcium.

But now an earth twin to this lunar rock has been found. J. V. Smith of the University of Chicago presented the results of analyses he and F. B. Windley of the University of Leicester, England, have conducted on rocks from the anorthosite deposit called Fistenaesset in West Greenland.

The rocks in this complex, unlike most earth anorthosites, have the same high-calcium, low-potassium and low-sodium content as does the lunar anorthosite.

"We are puzzled about these rocks," says Smith.

"Where did they come from?" The typical rock found in that area of Greenland has high-sodium and high-potassium contents and much less calcium.

The origin of anorthosites puzzles geologists because the melting temperature of anorthosites is some 200 to 300 degrees higher than the melting temperature of other igneous rocks or those formed from molten rock material. They have theorized that during the early history of the moon, for example, the outer shell melted while the interior was still relatively cool. Through some process, the plagioclase crystals separated from a melt in which several minerals were crystallizing. This anorthositic material solidified to become the lunar crust.

Orbital data from Apollo 15 show areas where there is a high ratio of aluminum to silicon in the rocks indicating the existence of plagioclase in many areas of the far side and several areas of the near side.

"If we could find on earth evidence of similar processes as we believe may have occurred on the moon," says W. C. Phinney of the Manned Spacecraft Center in Houston, "we would have an important key to understanding the accretional (growth) history and the initial crustal formation of the planets."

MAGNETIC MOON

One of the greatest surprises of the Apollo program is the discovery of magnetism in lunar rocks.

According to David W. Strangway of NASA's Manned Spacecraft Center, the moon rocks have a very stable remanent magnetism—as stable or more so than magnetism found in earth rocks.

Remanent magnetism is acquired when a melted rock cools and passes through a certain temperature called its Curie point (about 800 degrees C. for iron). At this point, the rock acquires a magnetism that is proportional to the magnetic field it is exposed to. Strangway finds that the rocks were exposed to a magnetic field for a period of at least a billion years.

What does all this mean? It means the moon either had

a magnetic field of its own or that it was exposed to another source for at least a billion years.

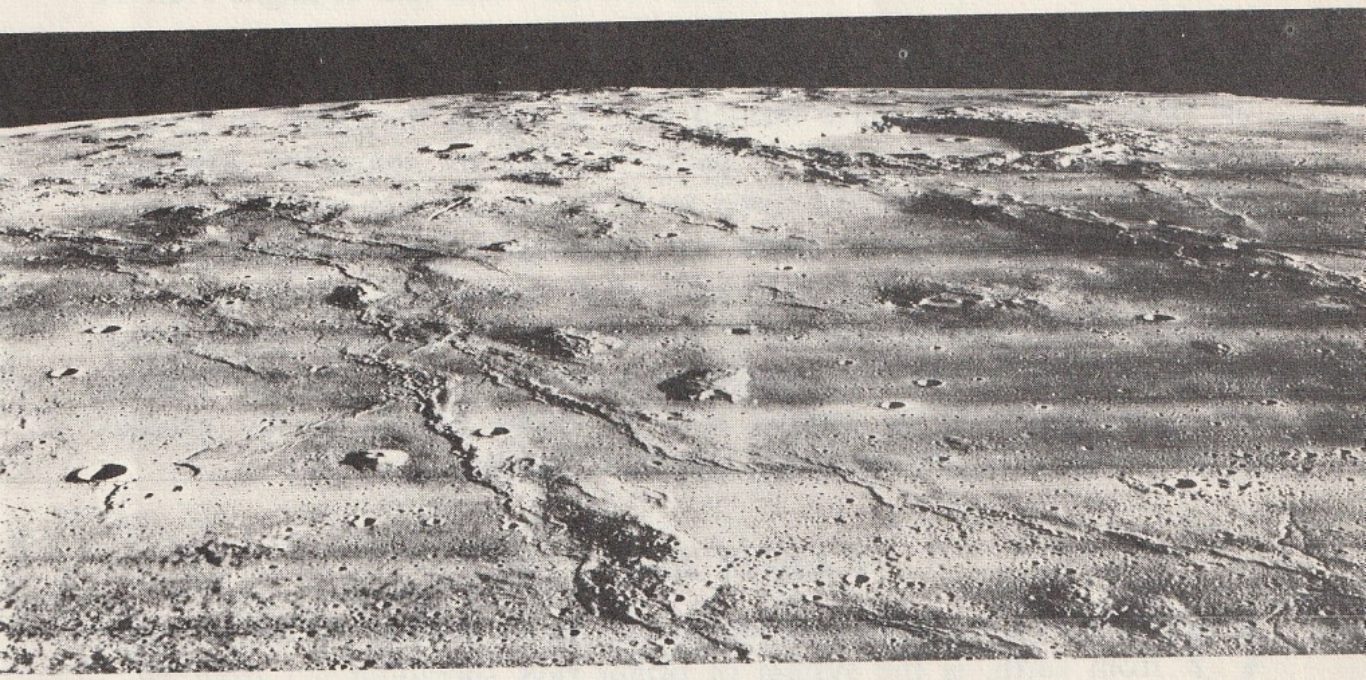
"We don't know the source of this field, although we suspect that there must have been a large-scale global field in the neighborhood of the moon during this time," says Charles P. Sonett, of NASA's Ames Research Center. "This discovery, in my opinion, will have profound bearing upon the development of lunar theory over the next several years," he said.

Volcanic Eruptions

BOTH EXTERNAL AND INTERNAL FORCES could have caused volcanic eruptions of much less violence than the giant geysers that resulted during the formation of the moon's seas. Some of the volcanoes erupted in chains along the edges of the great lava fields and escaped detection until only recently because they were so small. However, they appear very much like many of the extinct volcanoes that exist today in the Hawaiian Islands.

Most authorities were convinced that volcanic activity on the moon has long since ceased—and a good many scientists, indeed, questioned if it had ever existed—until the whole puzzle was reopened by analysis of the soil and rocks that the Apollo astronauts brought home.

One of the larger rock samples was found to be of fine-grained material clearly of volcanic nature, much like earthly basalt, and containing flakes of minerals. As with rocks on the earth, the sample was composed of oxides of seven elements: silicon, aluminum, magnesium, sodium, calcium, iron and titanium.



This photograph made by Lunar Orbiter II covers an area about as big as Massachusetts, Connecticut and Rhode Island, and shows an array of lunar domes. The domes confirm the fact that the moon once had a long and complicated period of volcanic activity.

Among other large samples brought back were lava-like rocks that were bubbled by gases emitted during periods of volcanic activity. All this would indicate that the moon certainly was alive and hot at some time in its history—and conceivably could still be "hot" today. But it is this very question—the possibility of still-active volcanoes on the moon—that provides some of the sharpest debates among scientists in the aftermath of the Apollo flights. Any definite proof of volcanism, and any geologic similarity between the earth and the moon, would tend to disprove the theory that the moon was once a wandering body that was captured by the gravitational force of the earth. Rather, such evidence would suggest the moon is either a spinoff of the earth, or that the moon and earth are sisters.

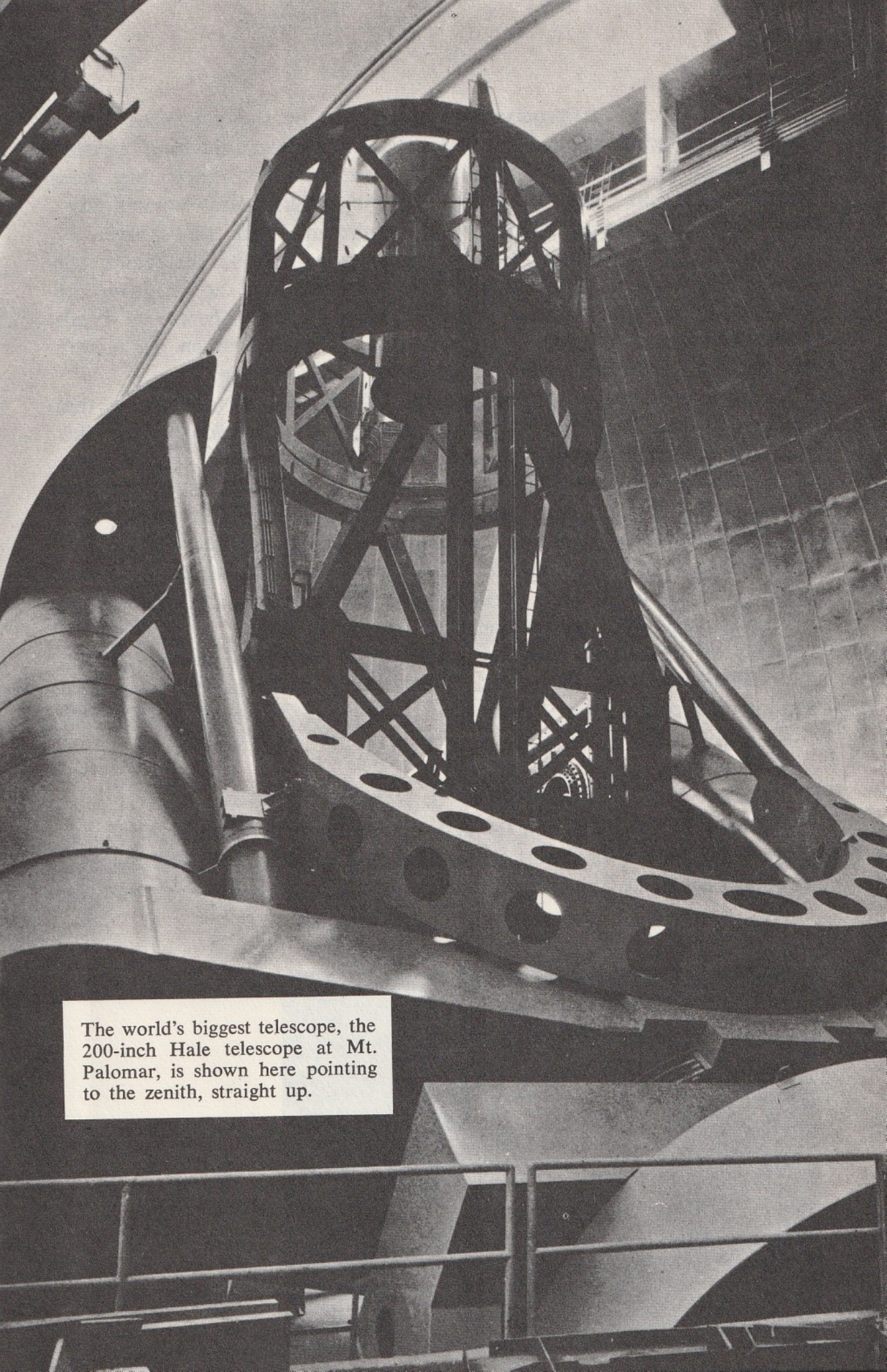
The Moon's Hidden Face

AS EVERY SKY-GAZER KNOWS, only one face of the moon is visible. Earth's gravity has locked onto the moon's near side, which always faces the earth. The hidden or far side has always been much of a mystery, leading to some strange theories in times past, such as that of the Dutch mathematician Hansen, who seriously suggested that all the lunar air and water had been drawn around to the far side, and it might even be inhabited!

No Apollo explorers ventured to the surface of the hidden side of the moon, but several have orbited over it, taking thousands of photos, in the wake of a long series of photo missions by unmanned American and Soviet spaceships. From these we have learned that with one exception, the two sides of the moon are much alike. The exception is that the moon's backside lacks the vast smooth plains that characterize the frontside. The general impression is one of a fantastically pockmarked surface lacking maria. The reason for scarcity of maria is not known, but it is reasonable to assume that the tricks played by the gravitational influence of the earth are somehow involved.

Craters and Rays

ONE OF THE MOST BEAUTIFUL SIGHTS on the moon's surface, as seen from earth, is the system of bright rays spreading out from near some of the major craters. These are seen in their full grandeur only at full moon when the sun's light is shining directly on the lunar disc. They are probably composed of volcanic glass and are like the delicate



The world's biggest telescope, the 200-inch Hale telescope at Mt. Palomar, is shown here pointing to the zenith, straight up.

strands of Pele's hair produced in abundance by the volcanoes in the Hawaiian Islands. This "hair" is very light and in Hawaii the long "tresses" are carried by the wind for great distances. On the moon they were probably deposited over its surface by the rushing gases coming from the vent of the volcano. This would require no lunar atmosphere.

The lunar rays stretch for long distances across the surface of the moon. The objects of which they are composed cast no shadows and always appear symmetrical, so they probably are spheres or beads (whether solid or hollow) of volcanic glass. They lie flat on the moon's surface and serve as brilliant mirrors of the sun's light.

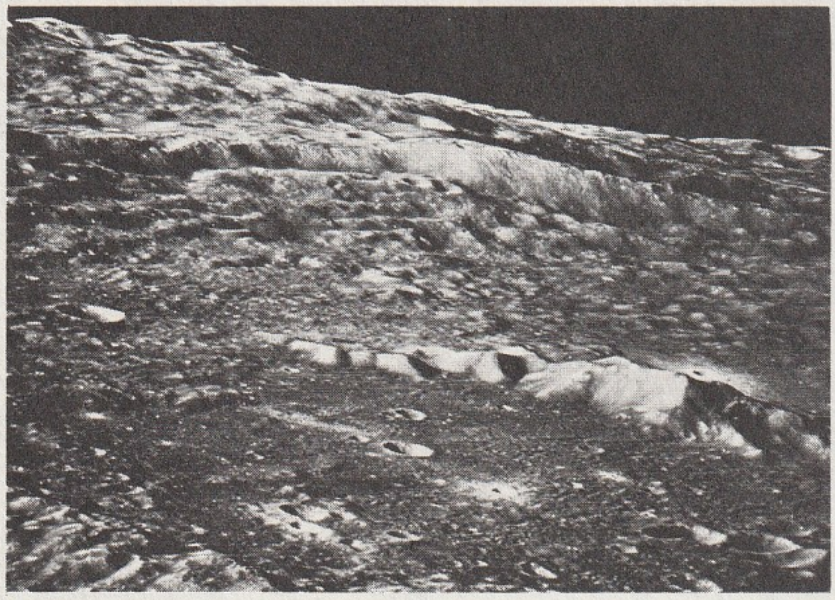
The most extensive and conspicuous of all the ray systems is that centered around the crater Tycho. Hundreds of rays radiate from this ring and stretch for great distances. They do not, however, obscure any of the objects they cross and so must be transparent or at least translucent.

Some rays can be seen coming over the edge of the moon, thus indicating where craters exist on the hidden side of the moon. Also sparkling in their brightness are the craters themselves, which are found on all parts of the moon's surface. They are on the plains, among the mountains, and even on the walls of the walled plains.

Some of the craters are on bright areas, possibly caused by the material ejected from the crater. The craters are the most conspicuous feature on the moon, just as mountains dominate the earth's landscape.

The Mass of the Moon

ASTRONAUT FRANK BORMAN and his companions aboard Apollo 8 were the first to report firsthand, on their December, 1968, orbital scouting mission to the moon, that the world there is one of clashing



The moon is a rugged place in spots, as these mountain ridges indicate.

10. THE EARTH OVER THE LUNAR ALPS

Standing on certain areas of the moon you might well see this type of landscape. The earth and stars and sky would appear to be very bright indeed because the moon has little or no atmosphere of its own.

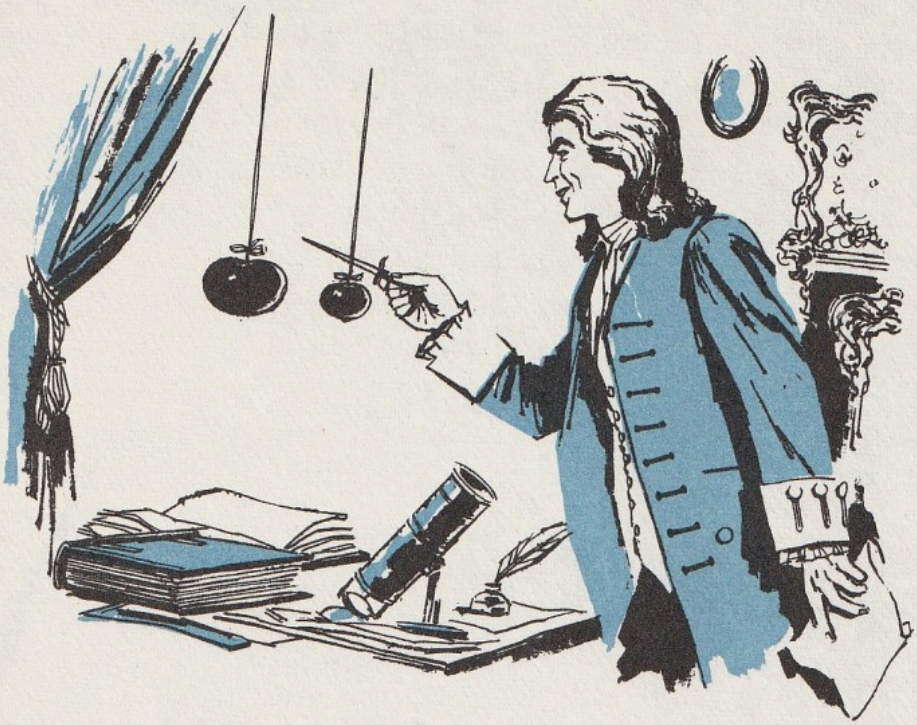
contrasts. Mountains 30,000 feet tall—higher than anything on earth —rise abruptly from the edges of vast, flat lava fields. Craterlets, the size of granite quarries, mark the floors of craters so wide that a man standing in the middle of one would not be able to see its rocky rim. Objects in shadow on the moon match the lightless sky in blackness, but the tops of distant mountain ranges reflecting the last, dazzling sunlight of a two-week-long lunar day are too bright to view directly. A mantle of fine, crumbly material covers everything. In the words of one Apollo explorer, this material looks like "dirty beach sand"

To establish further, and more clearly, how the moon got that way, consider its mass. Mass is simply the quantity of matter there is in an object, and is the same for that object measured anywhere in the universe. It doesn't mean much to know that the moon's mass is about 100 times less than the earth's, however, unless you understand why the difference between their masses is the major factor behind all their other differences.

This can best be understood in terms of the gravitational hold on things which a body's mass permits.This was worked out in the seventeenth century by Sir Isaac Newton. He found that objects exert pulling forces on one another, and called those forces "gravitation". The gravitational attraction two bodies have for each other varies directly with their masses and inversely as the square of the distance between them. That is, the greater their masses, the stronger the attraction, and the greater the distance between them, the weaker is that force.

Now, the moon's gravitational hold on things is about one-sixth as strong as earth's. This means that things *weigh* less on the moon than on the earth. Weight—which is frequently confused with mass—is a measure of the gravitational pull exerted on an object *on earth.* To understand the difference between mass and weight, simply remember

In this rare photograph of the back side of the moon, taken by astronauts in orbit, one can see the rugged terrain that marks that part of the lunar surface never seen from earth.

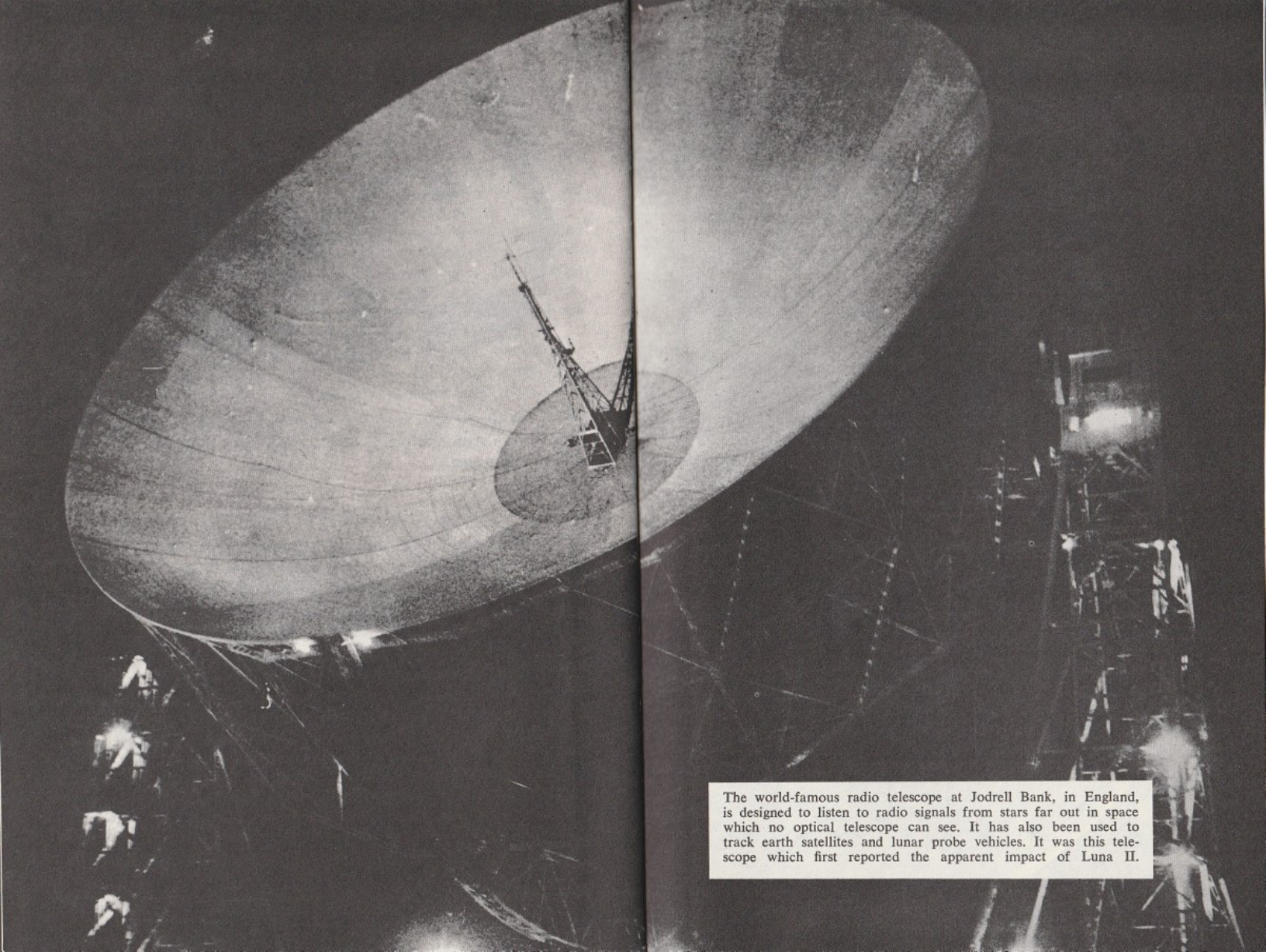


that a one-pound mass weighs a pound on earth, while it would *weigh* only about a sixth of a pound on the moon, even though its mass would still be one pound.

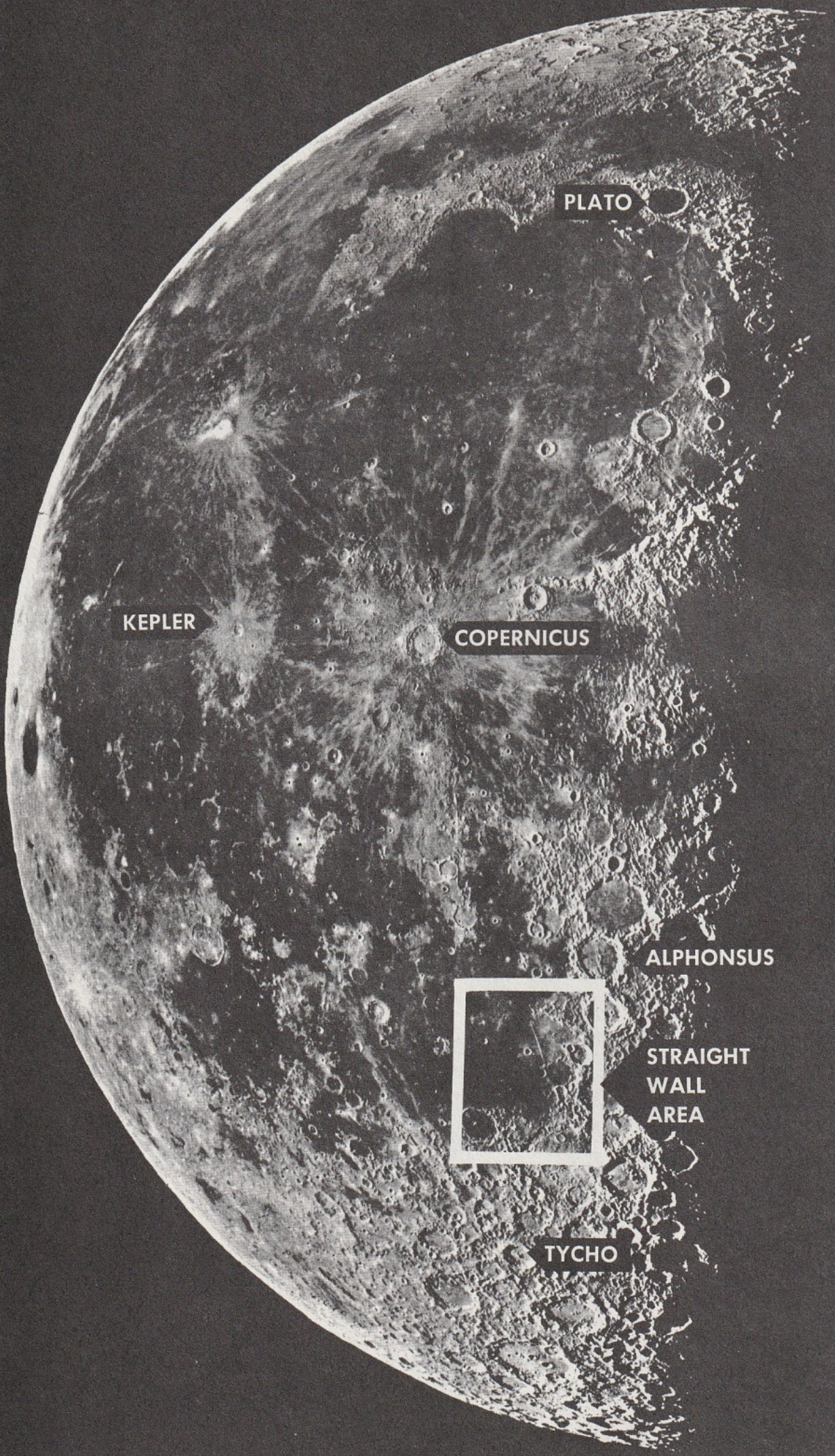
A Lifeless Place

THE SPEED that a space ship—or a gas molecule—must reach in order to leave the surface of a planet and keep going into space is called the "escape velocity". Escape velocity is determined, among other factors, by the gravitational attraction the body in question has for things, and, hence, it is a matter of mass. The less mass a body has, the smaller is its gravitational attraction for things, and the lower is the velocity an object has to attain in order to escape into space.

The earth's escape velocity is about seven miles a second, or roughly 25,000 miles an hour, which makes it necessary to use huge rockets with hundreds of thousands of pounds of thrust to get into space from here. The moon's escape velocity, owing to its smaller mass, is only about one and a half miles a second. This is weak enough to have permitted whatever atmosphere the moon had at its beginning to trickle off into space in less than a thousand years. Without an atmosphere, the moon had no potential for ever becoming a dynamic world like the earth, and was relegated—by its small mass—to the status of a static, lifeless place.



The world-famous radio telescope at Jodrell Bank, in England, is designed to listen to radio signals from stars far out in space which no optical telescope can see. It has also been used to track earth satellites and lunar probe vehicles. It was this telescope which first reported the apparent impact of Luna II.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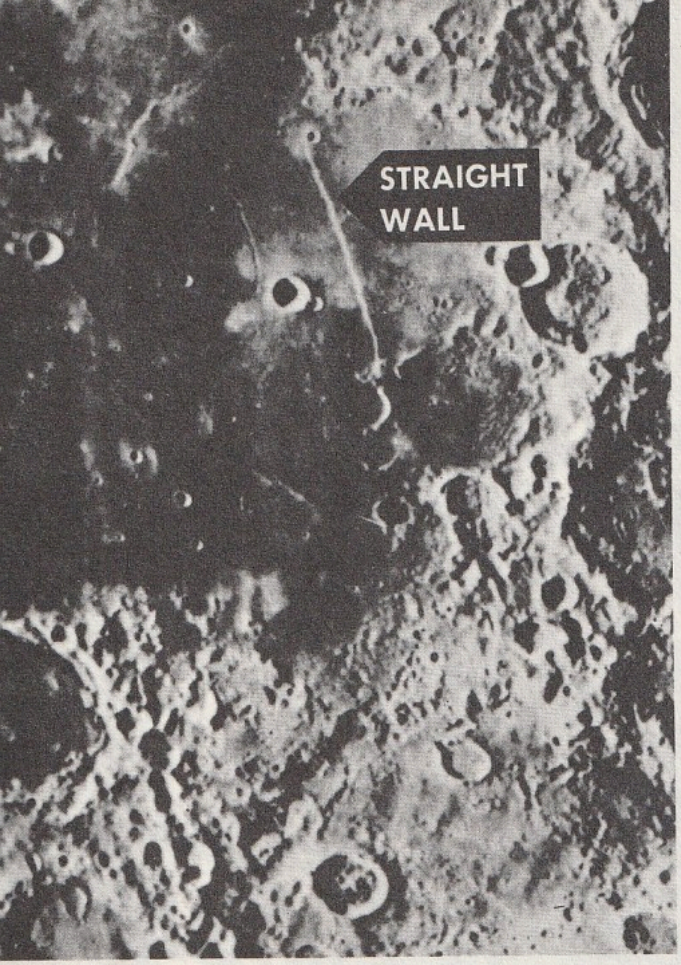
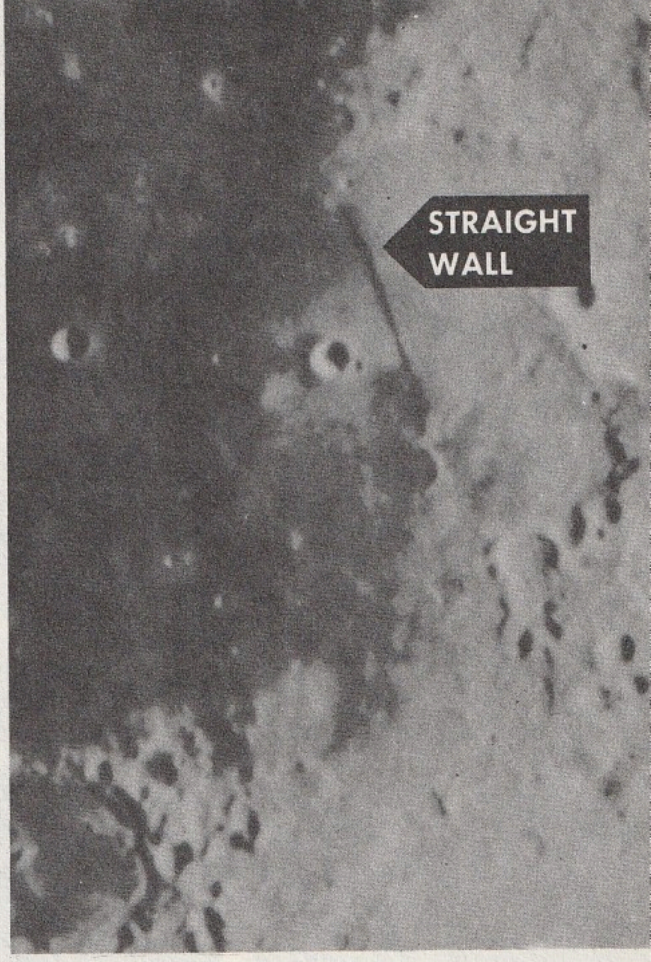
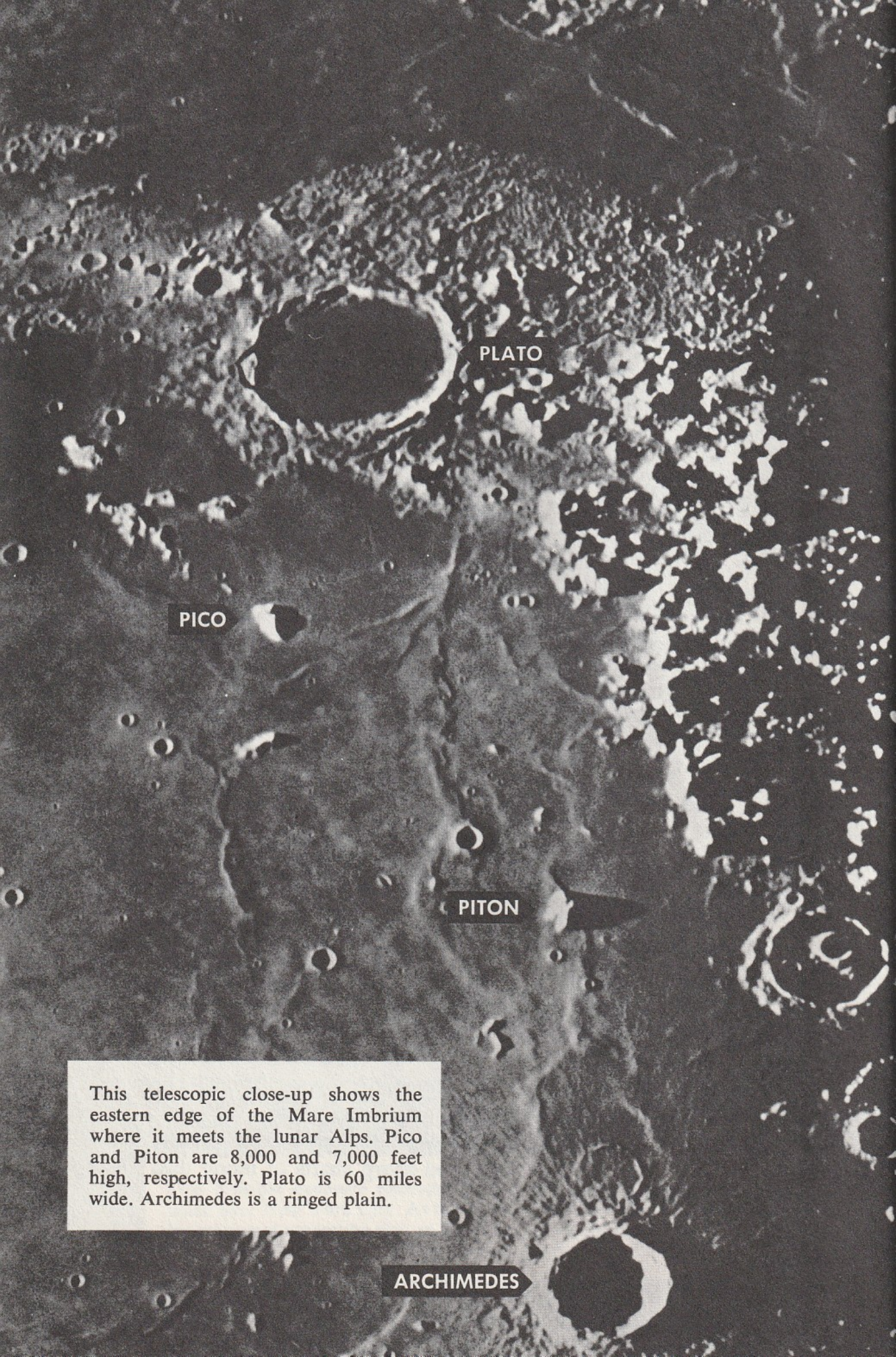




This photograph, taken at last quarter, shows how the Tycho ray system disappears during shadow conditions. In the boxed area lies Straight Wall. It is shown above, *left,* when illuminated from the west; *right,* when illuminated from the east. In fact, it is a cliff which faces west. Above the boxed area lies Alphonsus, where a Russian astronomer reported he saw the birth of a lunar volcano in November, 1958.

The absence of a lunar atmosphere has other effects. Our sky is blue because the gas molecules and dust particles in our atmosphere scatter and reflect light. The sky above the moon, however, has no such scattering atmosphere, making everything overhead a dead black except where untwinkling stars are visible. Day and night come quickly on the moon when the sun rises above or drops below the lunar horizon. There is no light of predawn or of twilight there because these are produced by an atmosphere which reflects light from the sun when it is below the horizon.

There is no such thing as "noise" on the moon, either, for sound requires air molecules to carry its waves. Should an atomic bomb ever be detonated on the moon, there would be no thundering explosion or characteristic "mushroom cloud" (this also requires an atmosphere). There would be just a bright flash, and sharp shafts of moon dust issuing from the latest lunar scar.



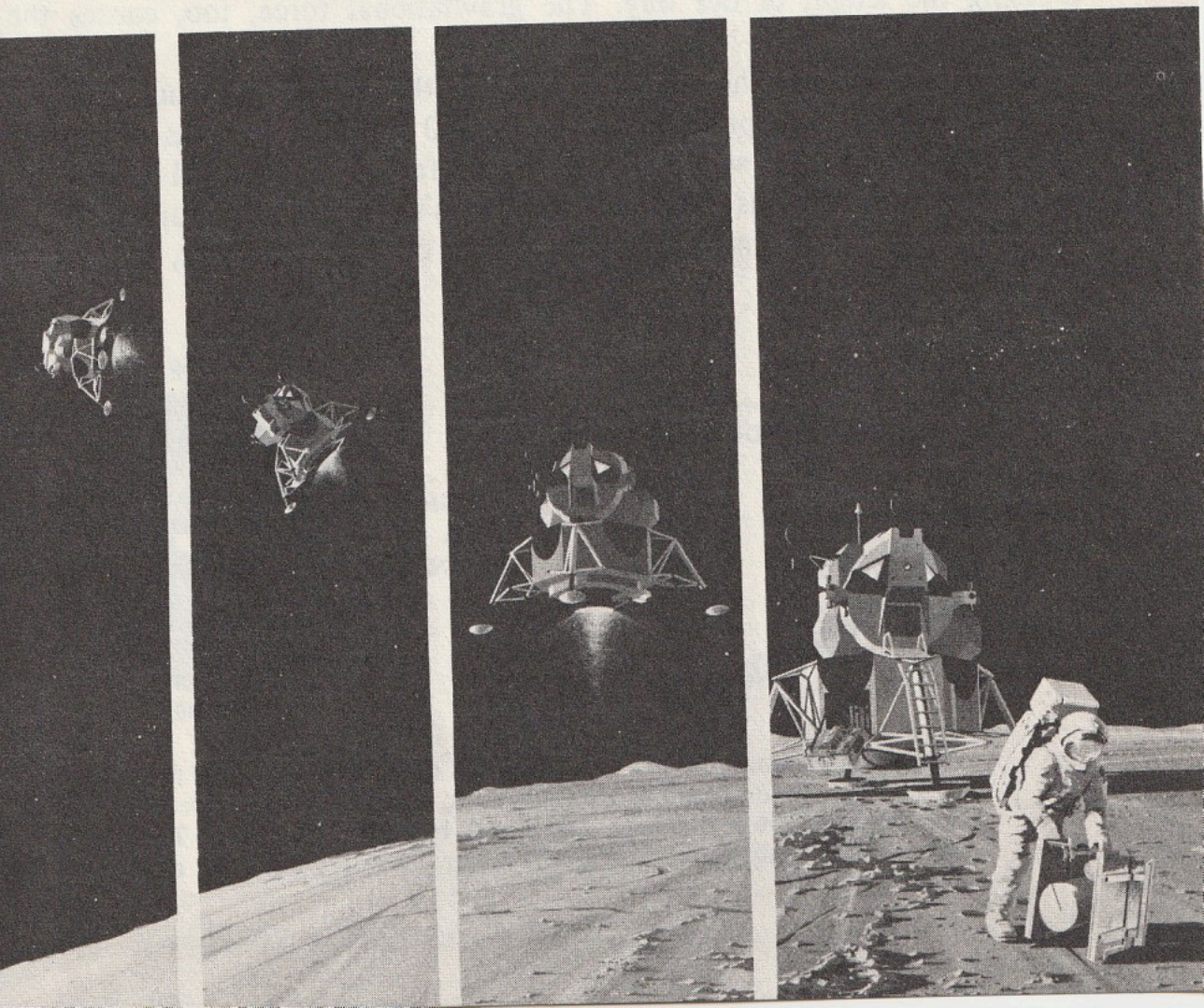
This telescopic close-up shows the eastern edge of the Mare Imbrium where it meets the lunar Alps. Pico and Piton are 8,000 and 7,000 feet high, respectively. Plato is 60 miles wide. Archimedes is a ringed plain.

No Weather, Either

BECAUSE IT HAS NO ATMOSPHERE, the moon cannot have any weather. No wind, no rain, no storms, no real seasons, just a relentless sequence of days and nights, each one about two earth-weeks long. But make no mistake about it, the moon's days and nights are rugged. Although all the space above the lunar surface has no temperature, the rocks of the moon reach temperatures as high as 250° F. under the direct, blazing sunlight. Midnight on the moon—when the sun has set—causes the temperature of the surface to plunge down to about 250° below zero F.

Forces bound up in such wide temperature variations, combined with the incessant rain of tiny meteorites and constant bombardment by cosmic rays, electrons and ultraviolet radiations from the sun during billions of years, have left their mark on the moon. This mark—uniformly distributed over more than 11½ million square miles—is the ever-

A panel of illustrations depicting the descent to the moon of the Lunar Module shows first its curving descent, then its hover, and finally a soft landing.



present dust we have heard so much about. Until Neil Armstrong first stepped foot on the moon, there had been some question about exactly how deep that layer of dust had grown. One scientist insisted it must be miles deep. It turned out—at Tranquility Base at least—to be only a thin film.

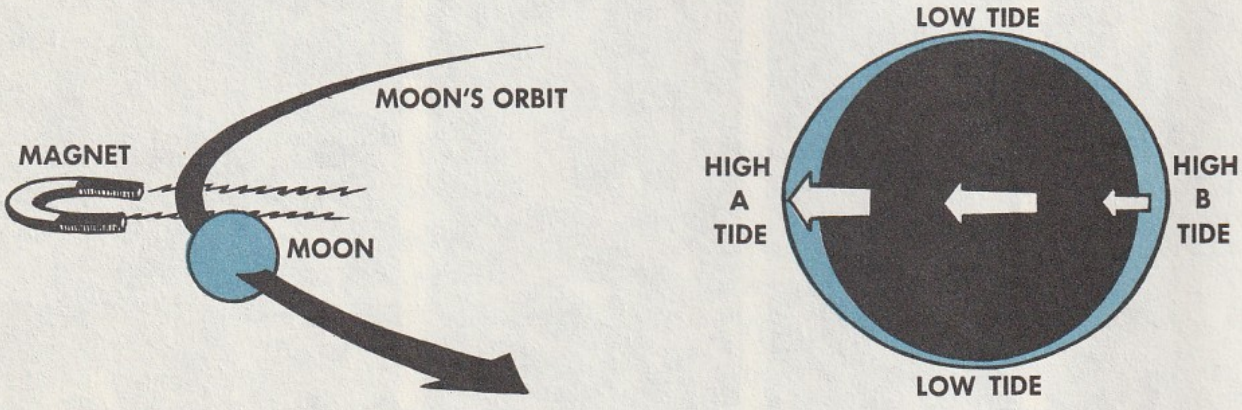
Influence on the Earth

OUR MOON is not the only planetary satellite in the solar system. There are at least thirty others: Mars has two; Jupiter, twelve; Saturn, nine; Uranus, five; and Neptune, two. Nor is our moon the largest. Both Neptune and Saturn have a larger one. Jupiter has three.

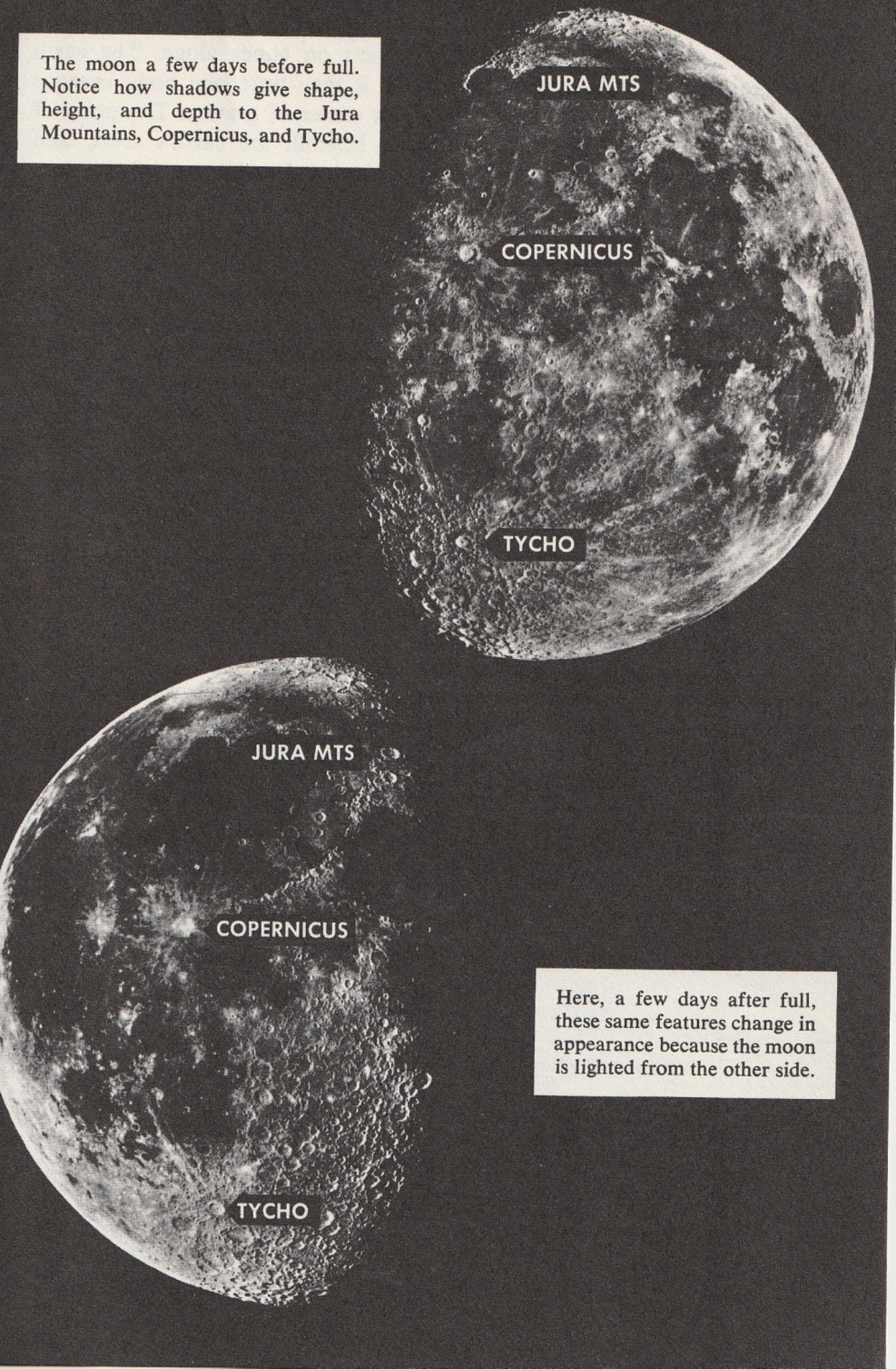
The principal distinction of our moon is that it is the largest one in relation to its planet; the moon's diameter is roughly 2,160 miles, about a quarter of the earth's. This means that the earth has been affected by its moon more than any other planet in the solar system.

The moon affects the earth through a powerful gravitational force acting over nearly a quarter of a million miles. This force moves the poles of the earth in the procession of the equinoxes, distorts the earth in what is called the "tidal bulge", and slows our planet in its spin, increasing the length of our day. The gravitational force, too, causes the tides.

No other force in the universe acts on the earth with such marked results. True, the sun pulls on the earth 160 times as hard as the moon does, but because the sun is 400 times as far away, its tidal forces are only about two-fifths as strong as the moon's. In fact, the sun is so far away from the earth and moon that it acts on them together, as though



The earth's ocean tides are caused by the moon's gravitational field. Where the greatest pull is exerted, at A, there is a high tide. At the center of the earth there is less pull, but more than at B. Thus the earth is "pulled away" from the water, leaving a high tide at B.



The moon a few days before full. Notice how shadows give shape, height, and depth to the Jura Mountains, Copernicus, and Tycho.

Here, a few days after full, these same features change in appearance because the moon is lighted from the other side.

they were a single body, more than it acts on either alone. The earth and moon actually behave very much as if they were one body because they have a "common center of mass", or center of gravity. The point of equal mass distribution lies 1,050 miles beneath the earth's crust, and this is the point that actually moves in a smooth orbit around the sun.

The Tides

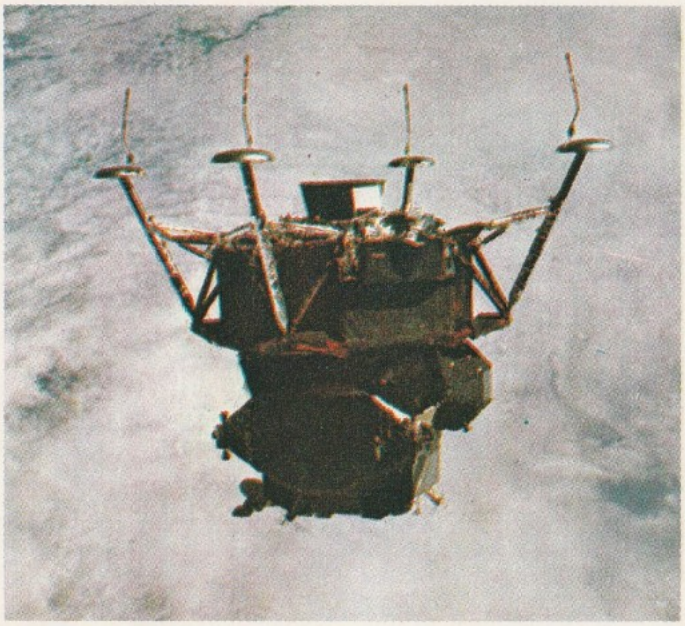
THE RISE AND FALL of coastal waters are caused by the gravitational attraction of the sun and the moon. But, as noted, it is the moon that has the chief effect on the earth's tides because the moon is much closer.

When the moon is directly over any particle of water, it tends to pull the water upward, or at least it would if it were not for the opposite pull of the earth. The pull of the moon on the water is only one ten-millionth as great as the pull of the earth. So the water remains in place.

But when the earth has rotated so that the moon is no longer directly overhead, the moon's pull on that same particle of water is partly vertical and horizontal. Because it is not directly opposed to the pull of the earth,

Almost as if standing vigil, a lunar module sits amidst the moon's Apennines. You can see bootprints and lunar "buggy" tracks in the foreground.

The spidery-looking Lunar Module, or LM, is the only part of the mammoth Saturn-Apollo "stack" that actually landed on the moon during America's several manned expeditions.



9. LUNAR MODULE IN FLIGHT

it is the horizontal pull that moves the water and causes high tide. For six hours and twelve minutes, the movement of the water is toward land, and at the end of that period high tide follows. Then for another six hours and twelve minutes, the water ebbs and low tide follows. It should be quite clear by now that there is an enormous amount of energy bound up in tidal forces.

Reaching for the Moon

MAN HAS PURSUED the conquest of the world about him in a logical way, building today's achievements upon the foundation of yesterday's accomplishments. This is evident in the history of man's attempts to overcome the force of gravity, from the invention of the balloon in 1783, through the advent of heavier-than-air craft in 1903, to the development of the modern rocket.

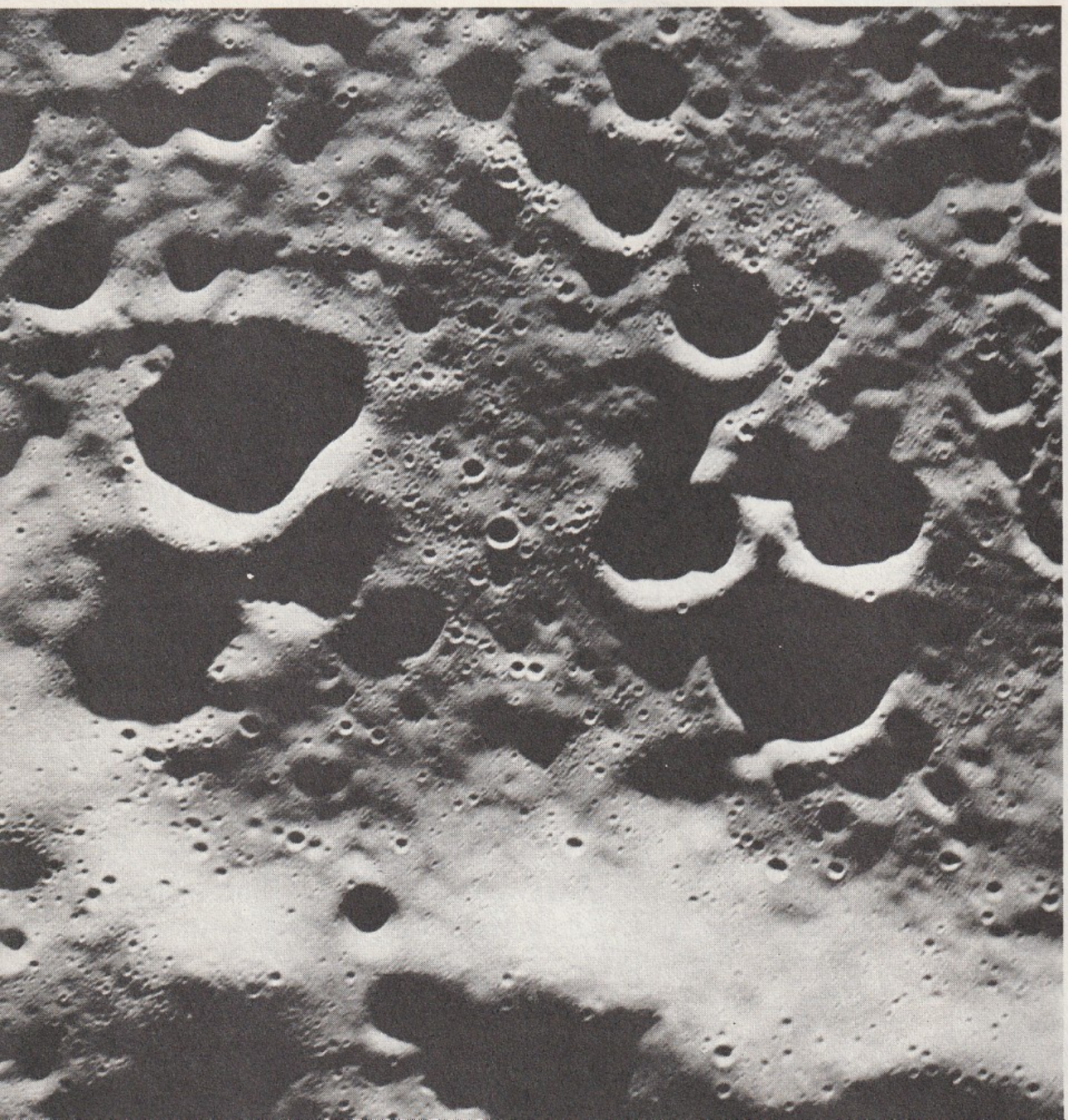
Balloons and airplanes have carried man higher than the tallest mountain on earth—indeed, at least five times higher. Now rockets transport him to even greater heights, as far as the moon, in fact. Thus it would appear that progress in flight proceeds in a vertical way.

This is not altogether true, however, for some of the most important achievements men have made toward leaving the earth for other objects in space have come about in a definitely "horizontal" way—that is,

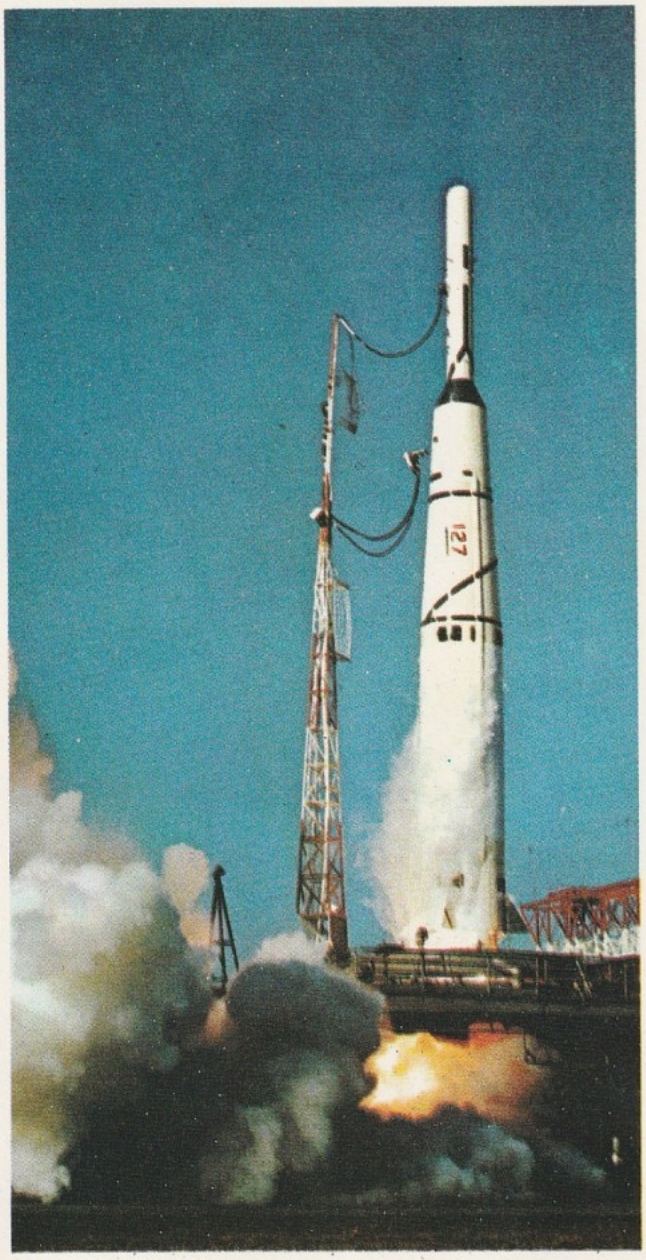
through inventions and discoveries quite unrelated to the problems of space flight.

For example, automation, or the automatic control of a mechanical or electrical system, has revolutionized industrial methods of making things. Miniaturization, by which components of machines have been made ever smaller and more compact, is another important factor in the growth of modern industry. At the same time, it has made possible the incorporating of complicated control systems into packages small and

This is a near-vertical photograph of the lunar surface on the far side of the moon, taken with a telephoto lens during an Apollo mission. The area covered by the photograph is approximately twenty miles on a side.

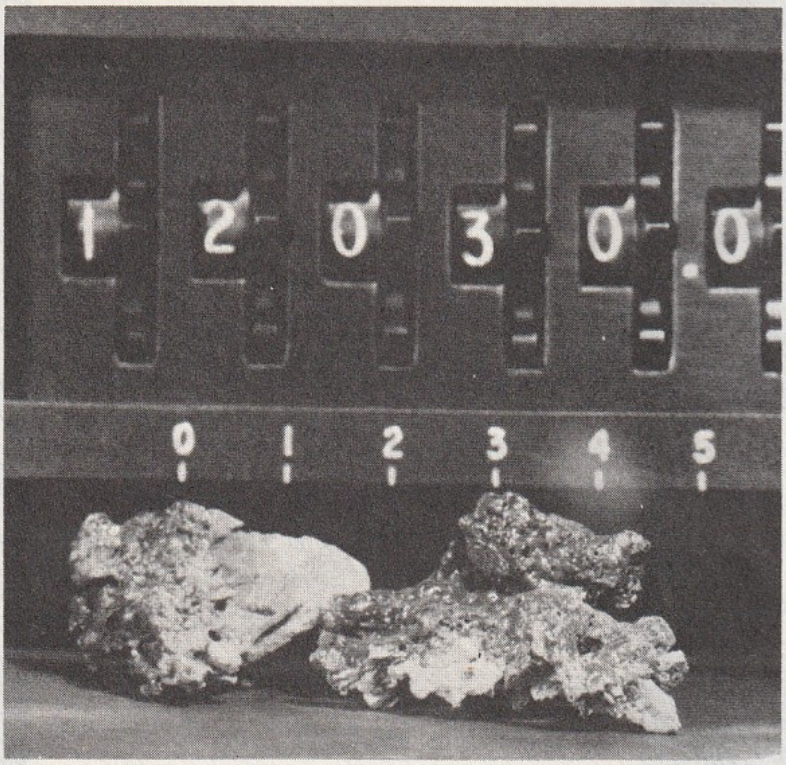


One of the many unmanned lunar probes launched by the United States. After "hard" crash landings came "soft" landings with instrument-only payloads. In 1969 came man's first touchdown.



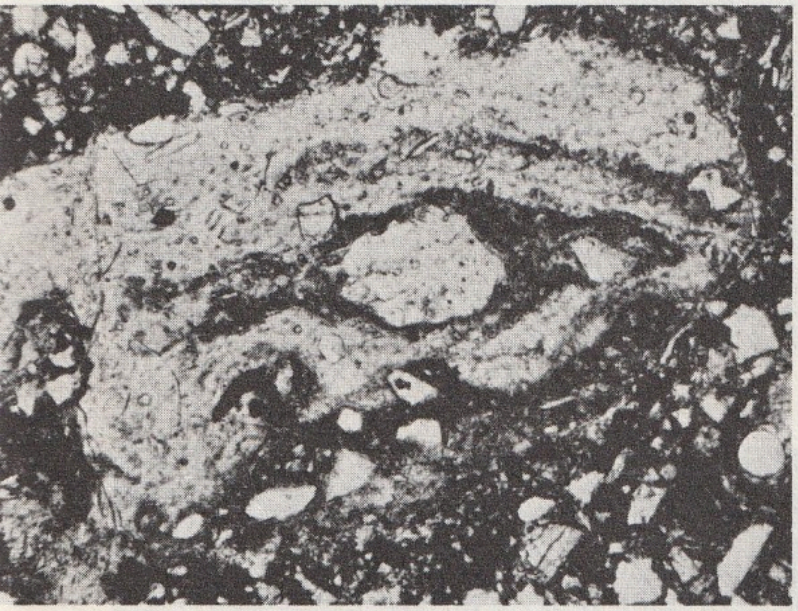
8. MOON PROBE ROCKET

Rocks collected on the surface of the moon are brought back to Lunar Receiving Laboratory at Houston, Texas, for special handling inside contamination-free room.

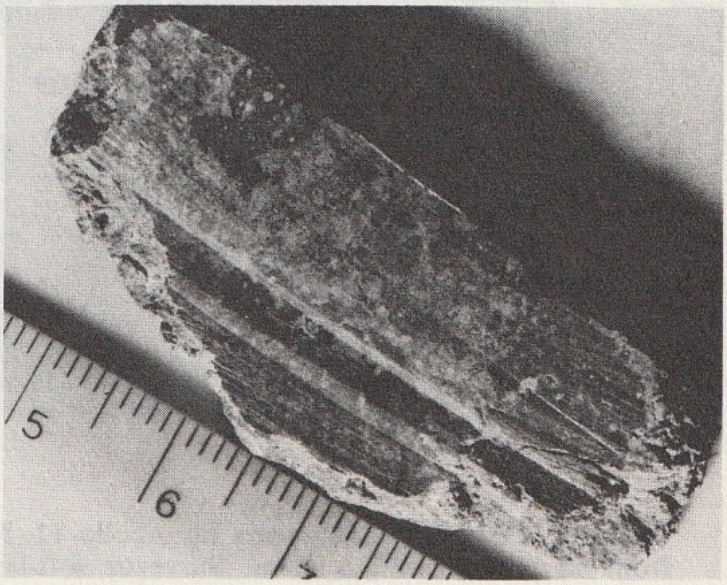


Close-up of lunar samples, consisting of chips and fines. These samples are tightly compacted, heavily coated with glass, and pitted.

light enough to be installed in rockets that can be sent off the ground and into space. New materials—featherweight metals, tougher-than-iron plastics—have been developed for modern automobiles and home appliances, and have also lightened rocket loads and at the same time given protection to the delicate instruments of rockets and space vehicles on trips through the earth's atmosphere. And not the least important have been developments in modern chemistry which have helped create new



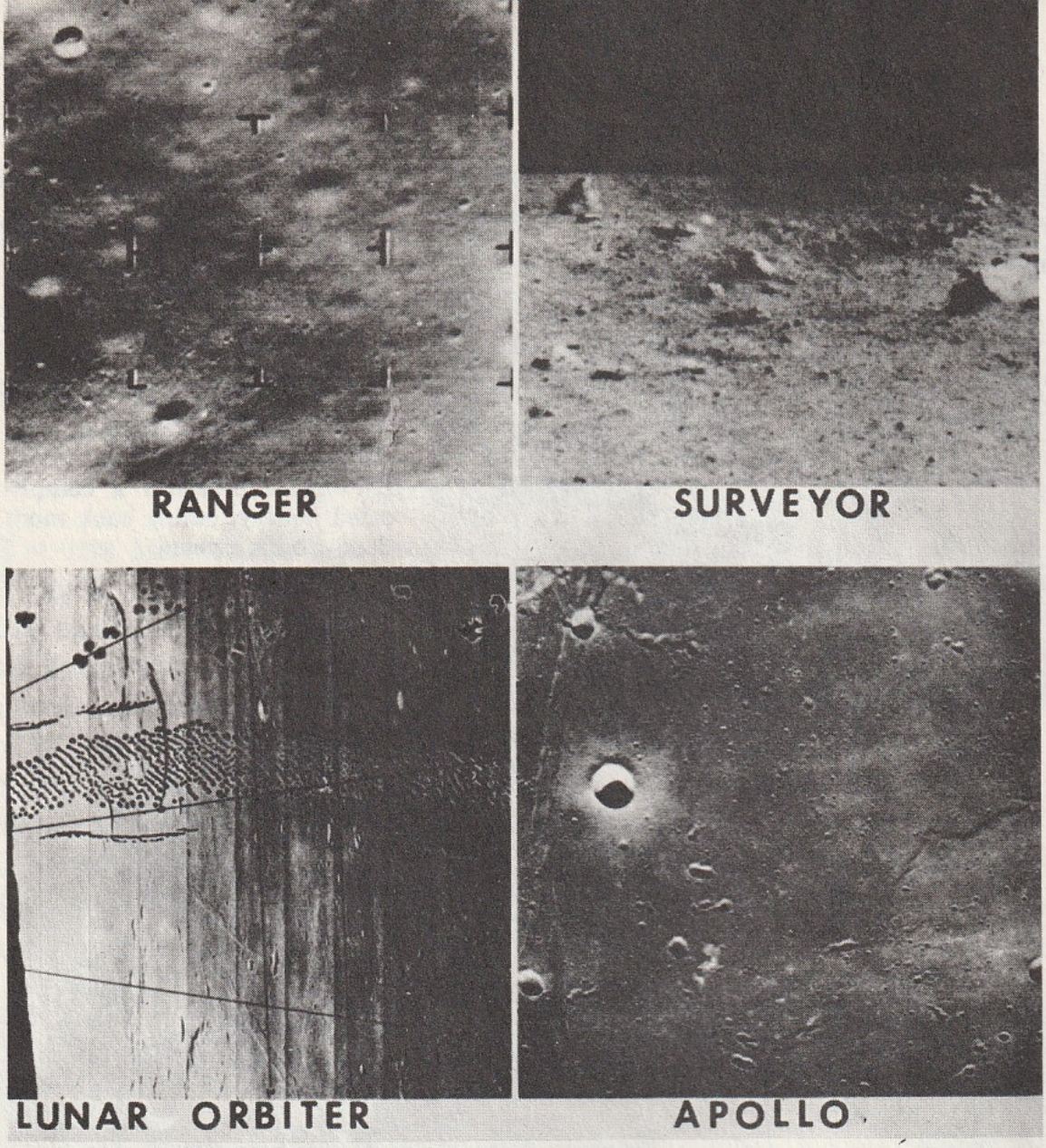
This moon rock was found to be radioactive, containing uranium, thorium and potassium. Its texture indicates a complicated history, dating back more than 4 billion years.



Under powerful microscopes, magnified 300 to 800 times, minerals in tiny fragments of moon samples are sorted and identified by their shade patterns. Photomicrographs also enable scientists to analyze rocks' crystalline structures.

drugs and fabrics—and have given today's rocketeers the powerful fuels needed to break the grip of gravity.

The space age was an inevitable consequence of man's indomitable desire to know, to reach out, to explore. The development of modern technology made it all possible. It is clear that the achievement of our first major space goal, conquest of the moon, was approached from the start in a steady, step-by-step fashion.



Views of the lunar landing area for Apollo 11. Ranger VIII took its photo from an altitude of 5.1 miles. Surveyor soft-landed and transmitted this photo of the surrounding area. Lunar Orbiter V photographed the site from an altitude of 59 miles. (The patterned line across the picture resulted from a mishap in developing aboard the spacecraft.) Apollo 10 during its orbits of the moon took this near-vertical photo.

First Photos from the Moon

FIRST CAME THE SO-CALLED LUNAR PROBES, unmanned rockets instrumented for the collection and transmission back to earth of information picked up in the vicinity of the moon. On 13 September, 1959,

the giant radio telescope at Jodrell Bank in England reported that the Russian lunar probe Luna II had struck in the area bounded by Mare Tranquilitatis, Mare Serenitatis and Mare Vaporum, after a journey of about thirty-five hours. On 4 October, 1959, the Russians launched Luna III and placed it in an orbit that included both the moon and the earth. Luna III photographed the moon's "hidden" side and transmitted those pictures back to earth.

The Russian moon program, after a long series of failures, once more turned in a startling success on 3 February, 1966, when Luna IX made the first "soft" landing on the moon and took some twenty-seven photos during its forty-eight-hour lifetime. The Russians said they got a good idea of the composition of the lunar surface from Luna IX.

Next came Luna X, another big Soviet success. It went into lunar orbit with very sensitive instruments. According to Soviet scientists it found virtually no magnetic field around the moon. To some experts this indicated that the moon lacks a liquid metal core like that of the earth. Other highlights of the Soviet program came in 1970 and 1972 when other Lunas "soft landed" on the moon, plucked up some stones and soil and returned safely to earth. Such feats could open the way to a new era of "robot exploration" of the lunar surface.

American "Eyes" on the Moon

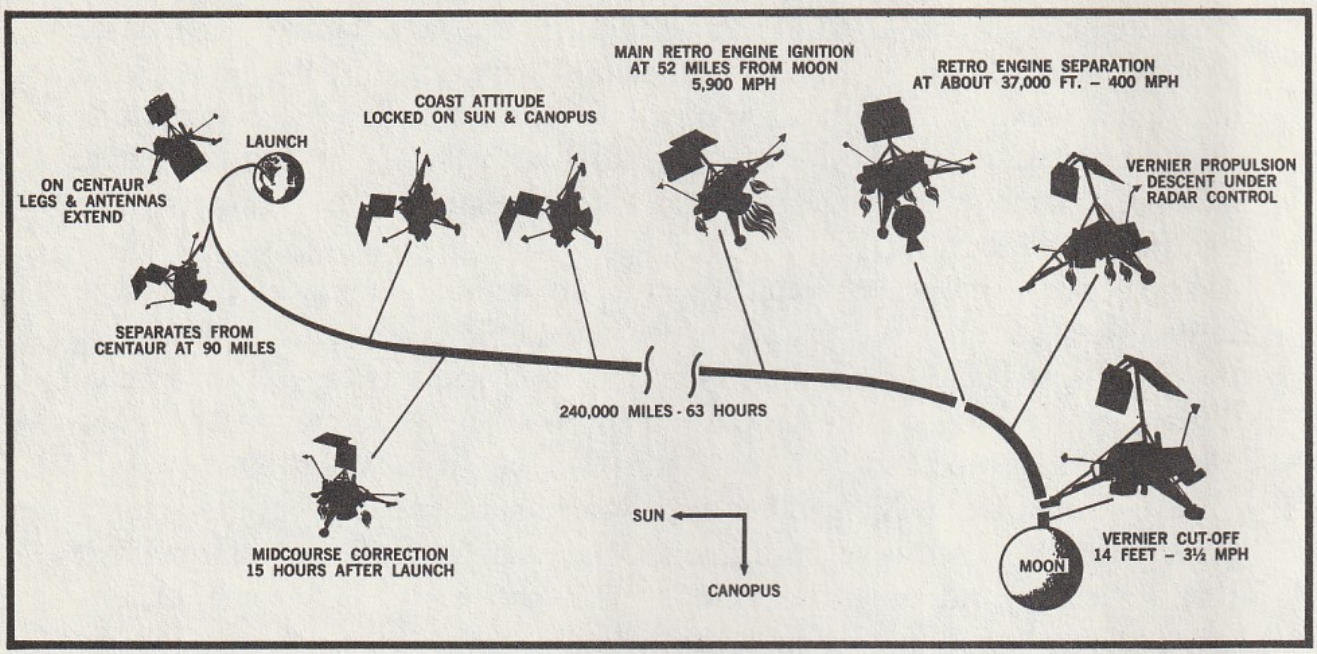
THE AMERICAN PROGRAM of exploring the moon through spacecraft photography, while late getting started, turned out to be far more productive than the Russians'—once U.S. scientists hit their stride with their Rangers, Surveyors and Lunar Orbiters.

Three successful Ranger shots alone—Rangers VII, VIII and IX in 1964 and 1965—sent back more than 17,000 close-up photos of the moon. A look at the first of the Ranger photos told scientists that craters, as everyone had suspected, were indeed the dominant feature of the moonscape. While only large craters can be seen through telescopes, Ranger photos showed craters as small as two feet in diameter.

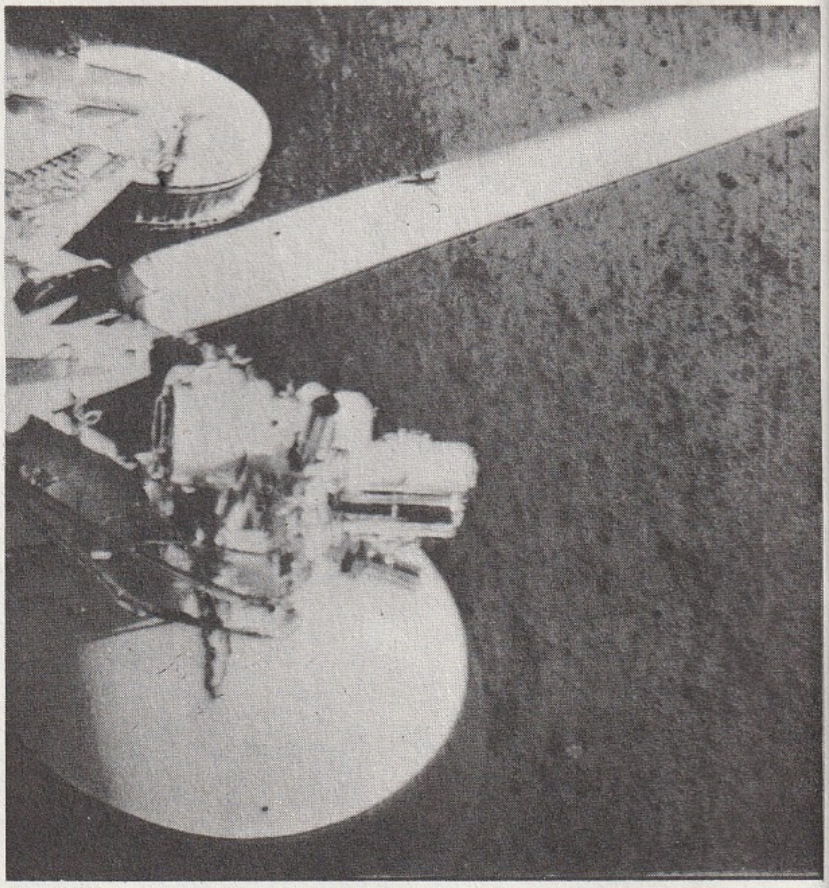
In all, five of seven Rangers aimed at the moon were on target, taking photos up to the very moment of impact, when they crash-landed as planned.

Five Lunar Orbiter spacecraft followed—accomplishing their missions of circling the moon, sending back some 2,000 photographs and charting almost every square mile of the hidden lunar back side.

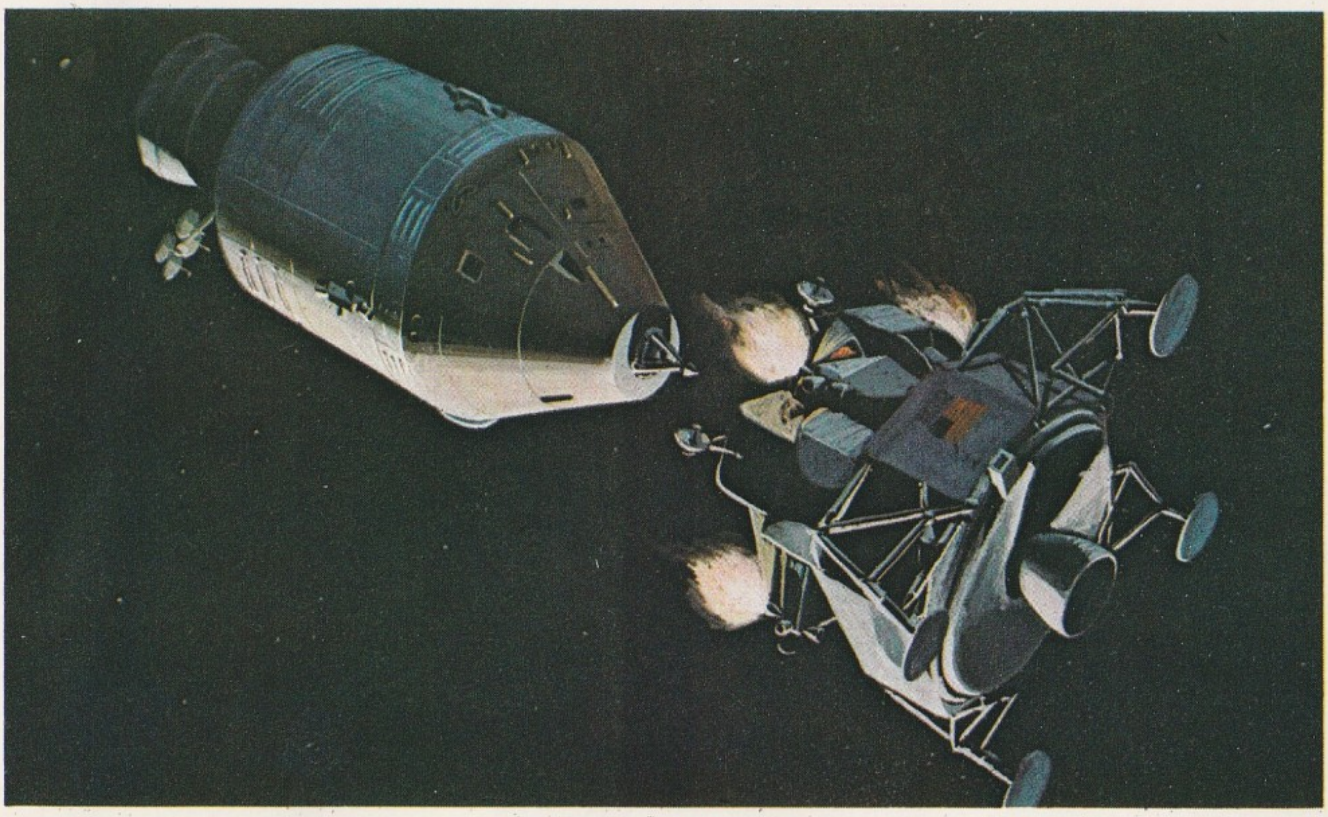
SURVEYOR FLIGHT TRAJECTORY



Surveyor's flight to the moon took sixty-three hours.



Surveyor I self-portrait was one of 144 TV pictures radioed to earth by the soft lander spacecraft during its first day of operation on the lunar surface. The disc-shaped object in upper left is one of Surveyor's three feet. Attached members are parts of the landing leg. Beyond the foot is an area where the foot disturbed the lunar surface, apparently making an indentation with a pushed-up ridge of granular material around it. The long white object is one of the spacecraft's two omnidirectional antenna booms. The large circular two-tone object at bottom left, with fittings mounted above, is helium container.



7. THE LM BLASTING AWAY

Artist's drawing shows the Lunar Module, its rockets firing, separating from the Apollo Command and Service modules. The LM carried two astronauts to a landing on the moon, while the Apollo craft continued in orbit overhead with the third astronaut.

Surveyors' Valuable Voyages

ANOTHER MILESTONE in unmanned exploration came 2 June, 1966, when Surveyor I made the first fully controlled soft landing. Retrorockets slowed the hurtling vehicle to a safe velocity of about 7.5 miles an hour and it touched down gently in the Ocean of Storms.

Accomplishments of the Rangers and Lunas were dwarfed by the performance of Surveyor I. From the time it landed on the moon to the lunar sunset thirteen days later, Surveyor transmitted no fewer than 10,338 television pictures to earth. The surface pictures, taken by a rotating camera, included both close-up and distance shots. Surveyor could see ten times as far as Luna IX, and it could pick out fine details twice as small as the Russian probe could detect. Surveyor made a nighttime photograph by "earthshine" which supplied information of great

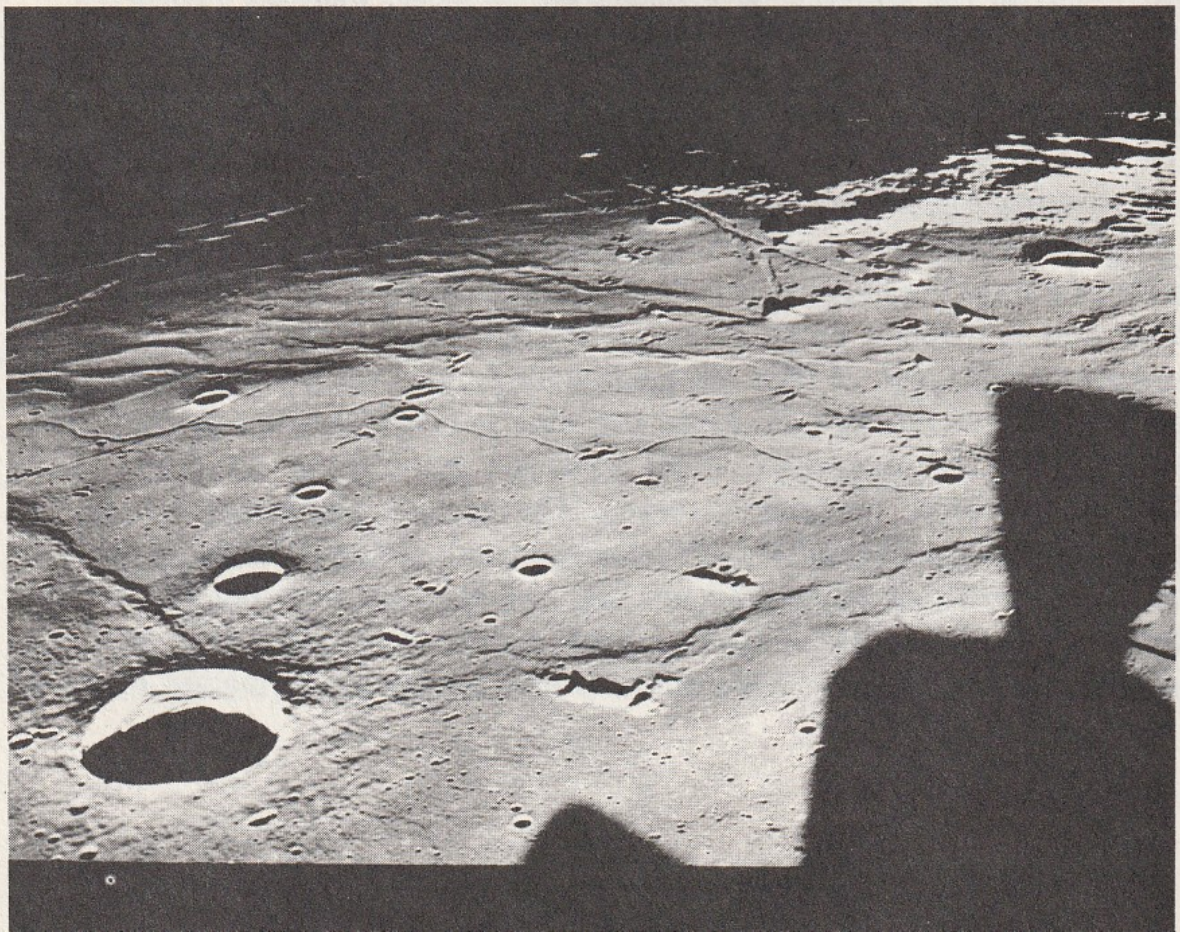
importance to weather scientists about earth's reflectivity of radiation from the sun. Another photograph—a famous one showing Surveyor's shadow stretched on the lunar landscape by the setting sun—provided hitherto unobtainable information about the moon's reflectivity.

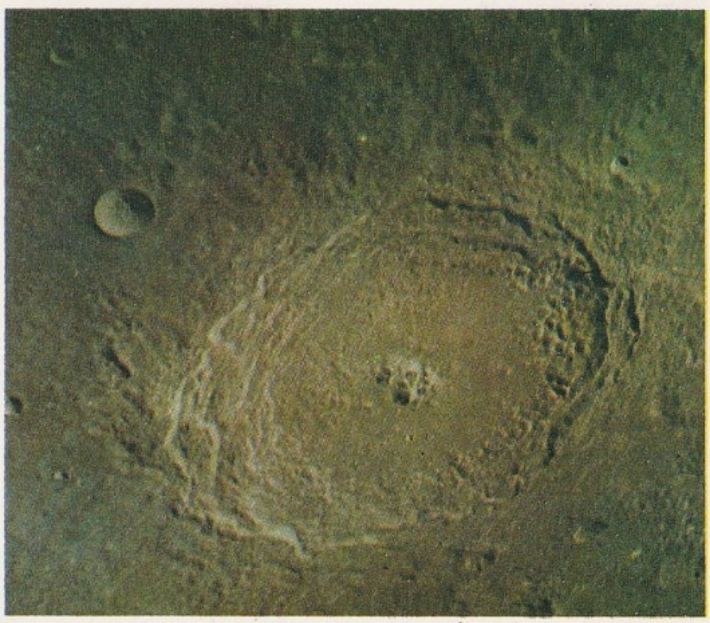
Four more Surveyors made successful soft landings on the moon before the program was completed in January, 1968.

Plenty of Secrets Left

FOR ALL THEIR ACHIEVEMENTS and contributions to knowledge of the moon, the Surveyors and Lunas still left much unexplained. They told scientists about the strength and appearance of the moon's surface, but little about its chemistry. Surveyor gave men a close-up look at lunar rocks, but tantalized them with the new question of why these rocks look the way they do. Investigation of the moon's deep interior—by creating moonquakes and recording the resultant shock waves that move through the rocks inside—had to await the more elaborate manned

The approach to the Apollo landing site is seen in this photograph taken from the Apollo 11 Lunar Module in lunar orbit. When this picture was made, the LM was still docked to the Command and Service modules.





Close-up of the moon from the Apollo 8 spacecraft, at Christmas-time, 1968. Apollo 8 scouted a safe landing place on the lunar surface for Apollo 11 in July, 1969.

3. A MOON CLOSE-UP

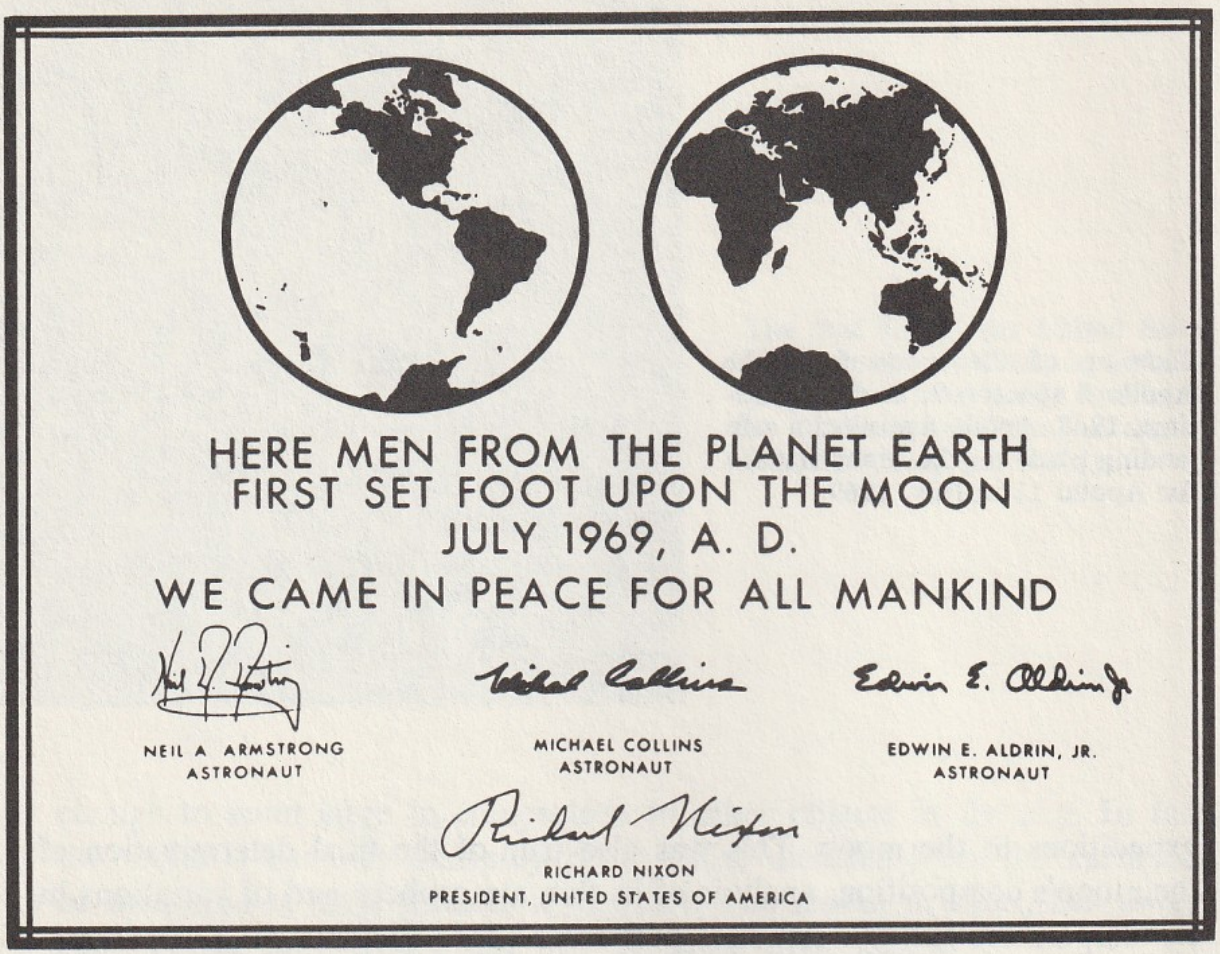
expeditions to the moon. This was also true of the final determination of the moon's composition, analysis of its thin atmosphere and of variations in its temperature and gravitational pull from place to place.

First Men on the Moon

MAN HAD LONG WONDERED what surprises the moon's surface held. But when man finally got there, he found no surprises of great magnitude.

True, it was a bleak and alien world that greeted the first men from earth. As they stepped in turn from the *Eagle,* astronauts Neil Armstrong and Edwin Aldrin found an environment totally unlike the earth's. Lack of air and water meant there were no winds, no rains, lightning storms or showers, no clouds; in fact, there was no "weather" at all. There was only the intense heat of the lunar day to be protected against by their $300,000 moon suits. Silence surrounded the explorers, for there is no atmosphere to carry sound waves.

Until the U.S. astronauts walked on the moon, space officials were not sure how easily man could get around on a surface where the gravitational pull is only one-sixth that of the earth's. Mr. Armstrong gave his own reply: "In the moon's weak gravity, man can live and work more comfortably than on earth or in the weightlessness of free space."



This is the plaque left on the moon by the Apollo 11 astronauts after their landing. It was fastened to the side of the Lunar Module descent stage, which was left behind when the astronauts took off to return to earth.

The closest thing to a surprise was the astronauts' discovery that the surface at Tranquility Base was compacted when they tried to scoop it, or drive experimental tubes a few inches beneath the surface. But Armstrong reported there was no sign of a rock layer underneath the dust, not even down to the bottom of a fifteen-foot-deep crater he scouted.

Even the color of the soil was pretty much as expected. Colonel Aldrin found the surface "a white chalky grey" when looking toward the sun, and a darker "ashen grey" when looking away from it.

The astronauts proved that lack of air was no problem—so long as man can carry a supply of oxygen with him and not use it all too fast. Their portable lifepacks performed as expected all the way.

The excellent physical condition of the Apollo 11 crew—including "third man" Michael Collins, who did not make the landing but stayed

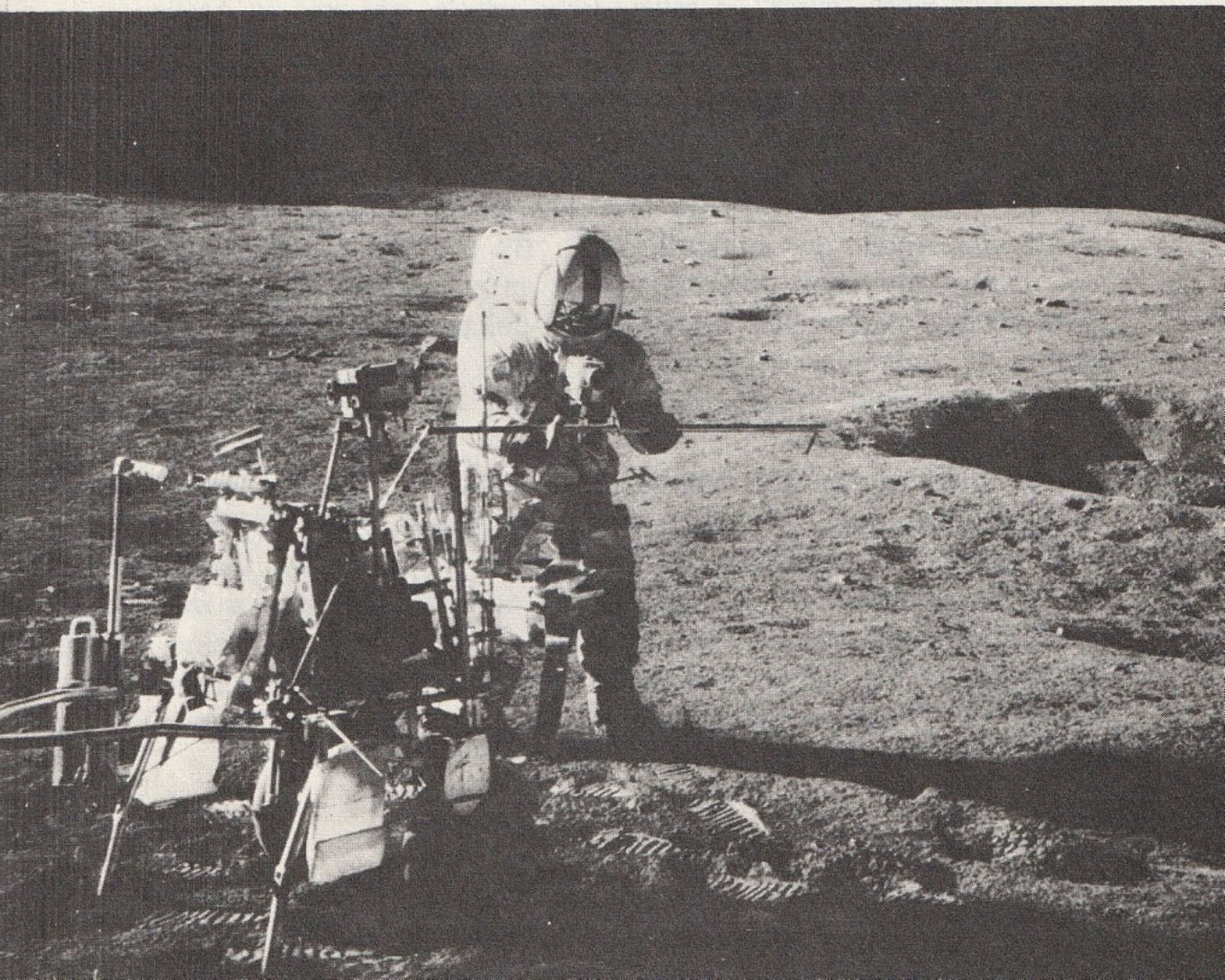
aloft in the orbiting mother ship—on their return to earth offered evidence that the moon harbours no fast-action, hostile lunar germs.

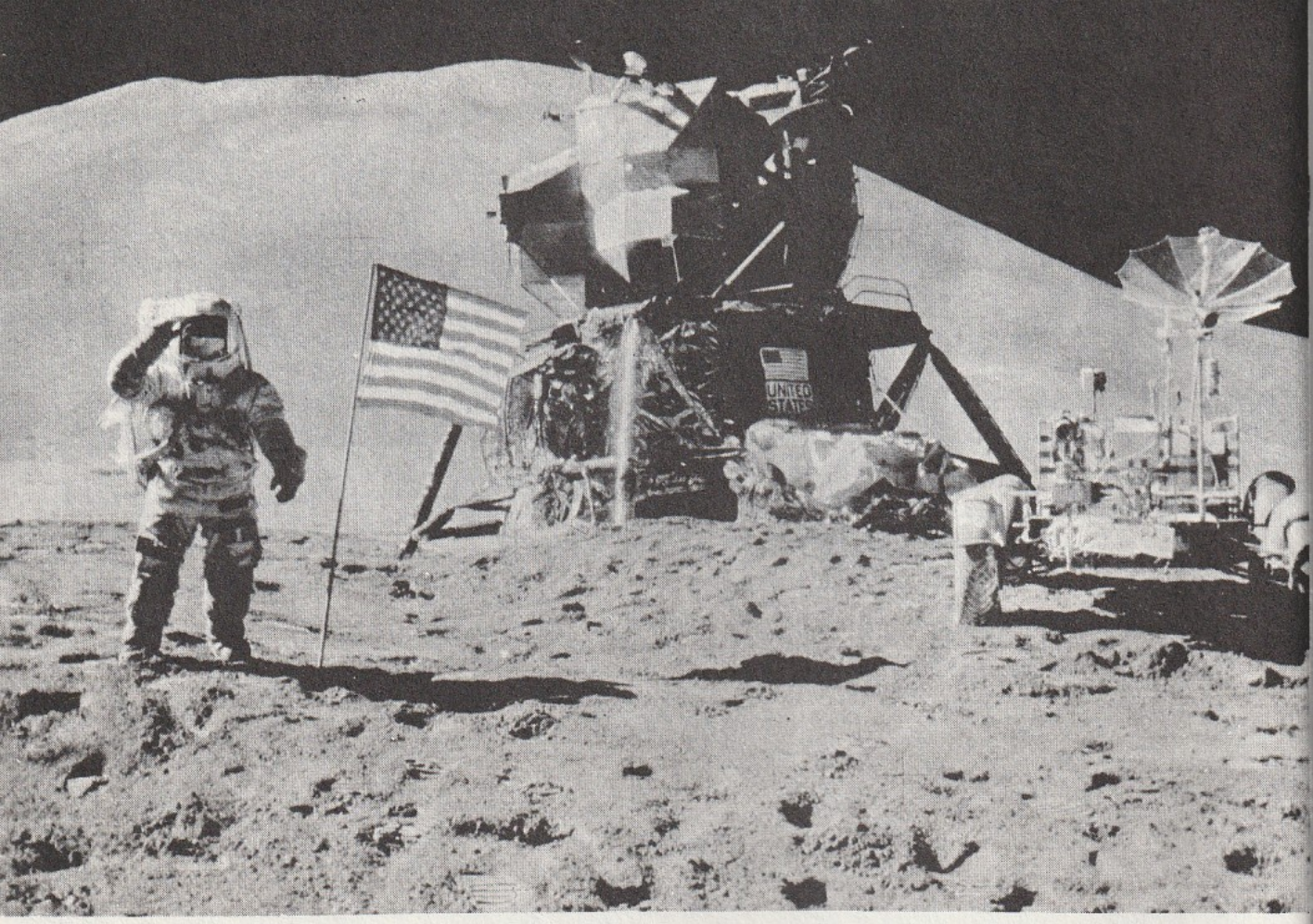
From start to finish, the voyage of Apollo 11 was without parallel. And, as astronaut Armstrong said as he first stepped foot on the lunar surface: "That's one small step for a man, one giant leap for mankind."

End of Apollo—What Next?

AFTER APOLLO 11 the landing on 19 November, 1969, of Apollo 12 seemed anticlimactic. It took Apollo 13 to reawaken people to the realization that moon travel was not so routine as it seemed. Apollo 13 took off from Cape Kennedy on 11 April, 1970, and was aborted after an explosion damaged the main power supply. That

Hand-drawn cart was used for first time on the surface of the moon during Apollo 14 mission in February, 1971. Astronaut Alan B. Shepard is shown assembling lunar hand tools taken from the transporter.





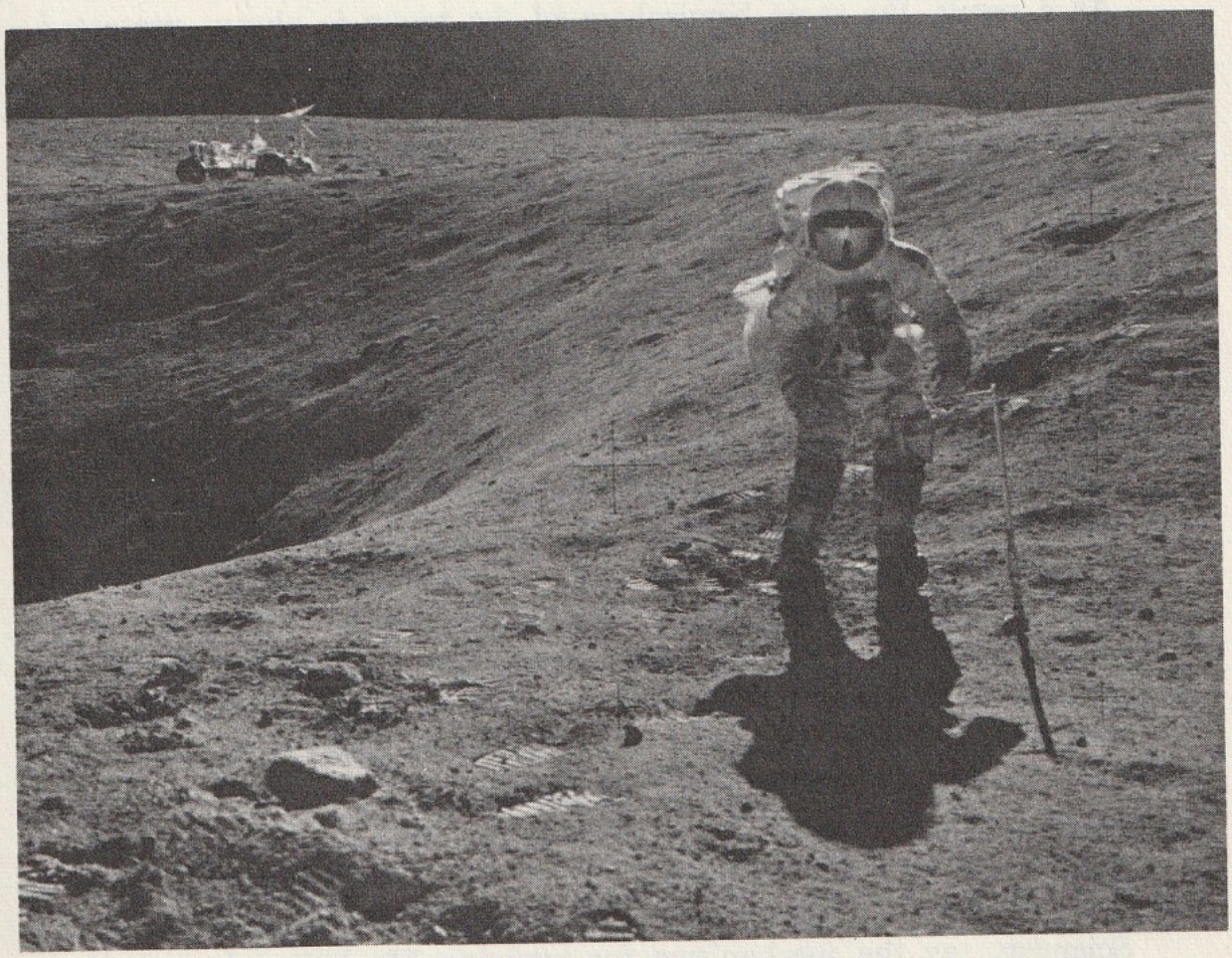
First moon "buggy"—a battery-driven vehicle—was used on Apollo 15 mission in July-August, 1971. Astronaut James B. Irwin is shown saluting American flag set up near the lunar lander. The lunar rover is at right. In background, three miles away, is Hadley Delta.

mishap—200,000 miles in space—set back the successful Apollo 14 landing until February, 1971. This was followed by Apollo 15 in July, 1971, and Apollo 16 in April, 1972. By the end of 1972 the American man-on-the-moon program was at an end. Lack of further Government money to continue the 25-billion-dollar project beyond Apollo 17 means an indefinite delay in U.S. plans. Estimates are that further moon exploration by Americans will not be resumed until the mid-1980s.

This does not mean that scientists have learned or even digested all there is to learn or digest from the Apollo missions. The fact is, those excursions on the moon have been so productive that scientists are overwhelmed with new data. It will be years—perhaps a full decade—before definite conclusions are reached as to the full value of the information. "The moon is a more complicated place than some of us thought it would be before we went there," says Dr. Paul Gast, a space agency scientist.

Looking ahead into the 1980s, some planners are talking about a space station in lunar orbit from which men will descend to any part of the moon for up to two weeks. Others predict there will be a permanent colony, in surface shelters, operating on the moon by the end of the century. Apollo 15 commander David Scott reported after his return: "The moon was very comfortable. We had three good nights of sleep. The one-sixth gravity still gives you enough sense of weight. Provided there was sufficient food, sleeping accommodations and a means of transport, colonization of the moon would be very practical."

No matter what lies ahead, man at this point of history can already take great satisfaction, for in just these past few years he has learned more about the moon than in all the centuries past.



Apollo 16 astronaut Charles Duke collects lunar samples at Descartes landing site in April, 1972. The parked moon vehicle is in the background.

In Brief: Useful Facts About the Moon

Distance The moon is our nearest neighbor in space, revolving round the earth at a mean distance of 238,857 miles—or less than ten times the distance round the earth's equator.

Dimensions The moon has a diameter of 2,160 miles, roughly one-quarter that of the earth. The density of the moon is 0.606 that of the earth.

Surface Gravity One-sixth that of earth.

Mass One-hundredth that of earth.

Orbit The moon's orbit has an eccentricity of 0.055, the perigee and apogee distances being 221,593 and 252,948 miles. The interval between successive new moons is 29 days 12 hours 44 minutes.

Rotation Tidal friction has resulted in the rotation of the moon being captured, or made equal to the period of rotation round the earth. As a result, the same hemisphere of the moon is always presented to viewers on earth.

Maria The seas, or maria, can be seen with the naked eye. No water has been found on the moon, but in the past there probably were "seas" of lava. The largest is the Ocean of Storms, with an area almost twice that of the Mediterranean. The Sea of Showers covers more area than Britain and France combined.

Mountains The highest chains are the Leibnitz and Dorfel, in the far south. They exceed 30,000 feet, and thus are higher than Mount Everest.

Craters In size, the craters range from vast formations such as Bailly—with a diameter of more than 160 miles—down to tiny pits at the very limit of visibility. They are found everywhere. The depths are great—29,000 feet in the case of Newton—but in relation to their diameters the craters are shallow. Clavius is 17,000 feet deep and 145 miles in diameter, so it is more like a saucer than a well.

Atmosphere The moon possibly may possess an infinitesimally thin atmosphere made up of argon and other chemically inert gases, released by the decay of radioactive potassium.

Temperature From almost 250 degrees above zero F. during the lunar day, to 250 degrees below zero F. at the lunar midnight.

Life No evidence of life of any kind has been found on the moon. Scientists say the mechanisms for evolving life halted long before forming even the basic chemical building blocks needed.

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